Extended Detention Facilities

(Source: Georgia Stormwater Management Manual, 2001)

Storm Water Management Benefits

Pollutant Reduction

Sediment	■
Phosphorous	▣
Nitrogen	□
Metals	□
Pathogens	□
Floatables*	▣
Oil & Grease*	▣
Dissolved Pollutants	□

Runoff Volume Reduction	□
Peak Flow Control	■

Key:
- ■ Significant Benefit
- ▣ Partial Benefit
- □ Low or Unknown Benefit

*Only if a skimmer is used

Implementation Requirements

Capital Cost	**Moderate**
Maintenance Cost	**Moderate**

1.0 Description

Extended detention facilities, also known as “detention basins”, are storm water structures designed to capture, temporarily hold, and gradually release a volume of storm water runoff to attenuate and delay storm water runoff peaks. The outlet structure of an extended detention facility is sized to limit the maximum flow rate. Extended detention facilities are designed to completely empty out. Extended detention facilities are not suitable as infiltration or groundwater recharge measures, and therefore do not significantly reduce runoff volumes.

These systems include those that are constructed above-grade as well as subsurface systems that are constructed below-grade. Figure 11-S1-1 shows a schematic of a typical extended detention facility and Figure 11-S1-2 shows a schematic of a typical underground detention structure.

2.0 Advantages

a) Cost effectively provides water quantity control to attenuate peak flows, limit downstream flooding, and provide some degree of channel protection.
b) Can also provide significant removal of sediments and particulate-bound pollutants such as phosphorous and lead.
c) Can provide an effective tool in metering flows prior to final storm water treament mechanisms.

3.0 Limitations

a) Limited water quality treatment for dissolved and soluble pollutants such as nitrogen and some metals. Most extended detention facilities lack a permanent pool, providing minimal treatment to soluble or dissolved storm water pollutants.
b) Susceptible to re-suspension of settled material by subsequent storms.
c) Surface systems may have poor aesthetics.
d) Subsurface systems can be expensive and may require a more aggressive inspection and maintenance schedule.
e) Surface systems often have significant space requirements.
f) Safety can be an issue during storm events as normally dry areas can quickly fill with water. Every effort should be made to exclude access in areas where significant potential exists for children to access the structure.
g) Surface systems may require construction of large embankments.

4.0 Siting Considerations

a) ***Groundwater:*** The design bottom of the basin should not be closer than one foot to the seasonal high water table elevation unless an impermeable geomembrane is utilized. Seasonal high groundwater levels above the elevation of the floor of an underground system will require a buoyancy analysis to determine the need for additional anchoring.

b) ***Land Uses:*** Land uses will both dictate potential pollutants-of-concern as well as potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport and contamination such as from petroleum hydrocarbons, the use of a liner is recommended. Some of these risks can be mitigated by using appropriate pretreatment such as an oil/water separator. An impermeable liner may also not be required depending on risk of downstream contamination. Consider potential safety issues in all adjacent land uses.

c) ***Site Slopes:*** Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume. Steep slopes may also present design and construction challenges, as well as significantly increase the cost of earthwork.

d) ***Flood Zones:*** Facilities should not be located in floodplains and shall not be located in floodways or tidal lands.

e) ***Buffer Zones:*** Facilities should not be located in regulatory buffer zones.

5.0 Design Criteria

The design of detention facilities is dictated by local storm water quantity control requirements or state requirements where RIDOT, RIDEM, or CRMC jurisdiction exists. Local or state regulations typically require that post-development peak flows be controlled to pre-development levels for storms ranging from 2-year through 100-year return periods. Control of more frequent events may also be required. The designer should consult the appropriate local or state authority for specific quantity control requirements, as well as the following references for guidance on the design and implementation of conventional extended detention facilities for storm water quantity control.

- Rhode Island Sediment and Erosion Control Handbook
- Earth Dams and Reservoirs, Technical Release Number 60 published by the Natural Resources Conservation Service for the design of embankments.

Facility designs may vary considerably due to site constraints, local requirements, or the designer's preferences. Design considerations for extended detention facilities are presented below and summarized in Table 11-S1-1.

Table 11-S1-1. Minimum Design Criteria for Extended Detention Facilities

Parameter	Design Criteria
Setback requirements	• 50 feet from on-site sewage disposal systems • 75 feet from private wells • 25 feet from a property line (this distance may be reduced with proper fencing or landscaping) • 20 feet from any structure • 50 feet from any residential structure • 50 feet from any steep slope below the berm (greater than 15%) • 25 feet from a designated CRMC buffer zone
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is the length at mid-depth (avg. top width+avg. bottom width)/2
Forebay	Forebays are highly recommended for extended detention facilities and sized to contain at least 10% of the WQV. Other alternative pretreatment devices can be utilized especially for subsurface systems.
Facility Volume	Facility volume shall be designed to reduce peak flows to desired levels. Facility volume shall also be designed to detain the WQV for a minimum of 36 hours unless Stoke's Law analysis demonstrates 80% TSS removal efficiency during the peak two-year storm flows.
Sediment Storage	Sufficient volume shall be provided to store a total of ten years of sediment in accordance with the Universal Soil Loss Equation as outlined in Appendix B.
Emergency Spillway	An emergency spillway shall be provided for any fill embankment. The spillway shall be designed to convey the entire 100-year storm across a stabilized spillway away from the embankment.

Embankment	• The embankment needs to be designed with a minimum one foot of freeboard during the 100-year storm. This freeboard can include the emergency spillway, however, at least six inches of freeboard should be provided above the 100-year storm water surface elevation in the spillway. These depths can be lessened for low risk embankments (short and no potential downstream risks). • For embankments with a maximum height greater than five feet, a minimum embankment width of 10 feet should be provided for maintenance access. Smaller widths can be employed for smaller embankments or alternative designs that can be demonstrated to be technically feasible. • Maintenance access shall be provided to the forebay and the structure such that heavy construction equipment can be used to remove sediment.

5.1 Forebay

A sediment forebay is required to minimize maintenance needs for extended detention structures. The purpose of the forebay is to provide pretreatment by settling out coarse sediment particles. This will enhance treatment performance, reduce maintenance, and increase the longevity of a storm water facility. A forebay is a separate cell within the facility formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

a) The forebay should be sized to contain at least 10% of the WQV and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often being three feet deep. Shallower depths should be evaluated such that flow through velocities do not exceed 2 ft/sec for all design storms. The goal of the forebay is to at least remove particles consistent with the size of medium sand. The forebay storage volume may be used to fulfill the total WQV requirement of this system. The forebay must also include additional sediment storage volume that may not be used for WQV calculations.
b) Alternative technologies sized to remove 80% of the total suspended solids load may be used in lieu of a forebay and its storage requirements.
c) The outlet from the forebay should be designed in a manner to prevent erosion of the embankment and primary pool. This outlet can be configured in a number of ways, such as a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the structure. The outlet invert must be elevated in a manner such that 10% of the WQV as well as the required sediment volume can be stored below it.
d) The forebay needs to have a minimum length to width ratio of 2:1 and a preferred minimum length to width ratio of 3:1.
e) Direct access for appropriate maintenance equipment needs to be provided to the forebay and may include a ramp to the bottom of the embankment if equipment cannot reach all points within the forebay from the top of the embankment. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.
f) A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.

g) A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it is designed to overtop. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the facility, the side slopes of the channel must be armored as well.

h) Sediment storage capacity shall be provided in the forebay as calculated by the Universal Soil Loss Equation in the *Rhode Island Soil Erosion and Sediment Control Handbook*. Adequate volume to store a minimum of ten years of sediment storage from the contributing watershed should be incorporated into the forebay.

i) Underground systems should also include pretreatment through the use of other structures designed to remove 80% of the total suspended solids loading. This is due to the problems with removing sediments and maintaining underground systems.

j) The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation that is based on Camp-Hazen:

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where:

$A_s =$ sedimentation surface area (ft^2)

$Q =$ discharge rate from drainage area (ft^3/s) $= WQV/86{,}400\,\text{sec}^*$

$W = 0.0004$ ft/s particle settling velocity recommended for silt

$E =$ sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Therefore, for the purposes of this manual and for evaluating storm water extended detention practices in Rhode Island, use

$$A_s = 5{,}750 * Q$$

5.2 Inlet Protection

a) Inlet areas shall be stabilized with riprap or other energy dissipation device to ensure that non-erosive conditions exist.

5.3 Extended Detention Storage

a) Hydrologic routing models based on accepted algorithms (e.g., storage indication method, TR-55, TR-20, HEC-HMS) shall be used to route design storms through the detention structure and determine outlet structure configuration and sizing. All routed storms shall be Type III with a 24-hour duration.

b) At a minimum, facility volume should also be designed to detain such that the WQV drains over a minimum of 36 hours unless Stoke’s Law analysis demonstrates 80% TSS removal efficiency during the peak two-year storm flows.

c) The following method can be used to calculate the size of the required orifice to release the WQV over the drain-out time of 36 hours. Alternative methods would be considered on a case by case basis.

$A = Q / Cd(2gh)^{1/2}$ where, A = orifice area (ft^2)
Q = average rate of discharge (ft^3/sec) = WQV / 129,600 sec (36 hours)
g = gravitational constant (32.2 ft/sec^2)
h = average depth of water above the center of the orifice (ft), where h = (maximum elevation of WQV stage – elevation of center of orifice) / 2
Cd = orifice coefficient (assume = 0.6)

d) The inlet and outlet of the facility should be positioned to minimize short-circuiting. Baffles and internal grading can be used to lengthen the flow path within the facility. A minimum length-to-width ratio of 3:1 is recommended for path from inlets to outlet. One exception would be allowed for minor inlets where less than 10% of the total volume of runoff enters the structure.
e) Ideally, the number of inlets should be minimized and placed at the most hydraulically remote points in the structure in order to minimize the potential for short circuiting.

5.4 Stoke's Law Analysis (Alternate TSS Removal Analysis)

Extended detention portions of the pond should be sized to remove 80% of the total suspended solids (TSS) entrained in storm water runoff. The geometry of the structure should be evaluated using Stoke's Law to confirm 80% removal. The purpose of this section is to outline an alternative approach from what is described previously to size a storm water pond.

The following two equations can be used to determine the length of a pond whose settling area is established by A = 120Q. The two equations are provided to allow designers to quickly determine and conceptually fit stormwater ponds into project sites. Generally speaking, long, thin settling areas provide for more effective settling of solids and reduce the total area required to site a pond.

If the settling area is square then:

$$Pl = 87.6Q^{1/2}$$

where:

Pl = pond length; and
Q = 2-year peak flow rate for particular storm event

If the settling area is rectangular then:

$$Pl = 120Q/Ws + 7Ws; \text{ and}$$
$$Ws = (Pl \pm (Pl^2 - 3360Q)^{1/2})/14$$

where: Pl = pond length; and
Q = 2-year peak flow rate for particular storm event
Ws = settling area width = pond width; and

Note that the length of the settling area must be greater than the ponds depth.

Discussion of Assumptions: The Stoke's Law can be used to determine the percentage of TSS that settles in an extended detention facility prior to discharging through the facility's outlet. Stoke's Law is defined by the following equations:

$Q = v_0 * A/w$ where, Q =2-year peak flow rate for particular storm event, cfs
v_0 = reference settling velocity, fps
A = surface area of settling zone, ft^2
w = wind shear constant 1.2

And, $v_0 = (g(\rho_s - \rho)d^2)/18\mu$ where, v_0 = settling velocity, fps = 0.01 fps*
where, g = acceleration of gravity, 32.2 ft/sec^2
ρ_s = density of the particle, lb sec^2/ft^4
where, $\rho_s = \gamma d/g = G_s\gamma_w/g = 5.14$ lb sec^2/ft^4
G_s = specific gravity of sand (assume mostly quartz in composition, 2.65)
γ_w = specific weight of water (assume, 62.43 lb/ft^3 at 40°F)
ρ = density of water (assume, 1.94 lb*sec^2/ft^4 at 40°F)
d = diameter of spherical particle, (assume, 0.0035 ft)
μ = absolute viscosity of water, (assume, 3.23×10^{-5} lb*sec/ft^2 at 40°F)

*This value is only appropriate where street sand is the primary source of sediment load. Other land uses will require a separate analysis.

Based on these evaluation criteria, the Stoke's Law analysis can be simplified to the following equation:

$$A = 120Q$$

Refer to *Derivation of A = 120Q*, below, for a detailed discussion of Stoke's Law application to detention facilities. The settling area of the structure is adequate if it is greater than or equal to the area calculated by this equation.

Derivation of A = 120Q: Based on Stoke's Law, particles will settle in quiescent zone at a velocity that can be calculated using the equation A = 120Q

This settling velocity (Vs) is dependent on the downward force of gravity, particle density in comparison to water, particle diameter (assuming a spherical shape) and water viscosity in the settling zone. Assuming that water is at 40^0 F and using equation $v_0= (g(\rho_s-\rho)d^2)/18\mu$, settling velocity for a particle of sand of diameter 0.00035 feet (i.e., 70 um) is 0.01 feet per second. This particle is called the reference particle.

For extended detention basin design, plug flow conditions are assumed to create a condition of relative quiescence where suspended particles (e.g., sand) match the velocity of water in the settling zone. Plug flow can be defined as an area where flow lines are parallel in three dimensions and of a constant velocity. Plug can also be defined as area where laminar flow occurs in all planes throughout the depth of flow at constant velocity. Where such conditions occur, particles of sand will drop out of suspension. Larger particles of the same and greater density will also drop out of suspension.

If settling velocity is set equal to velocity of flow in the settling area (i.e., Vs = Vo) then particles will settle out at a trajectory of 45^0 and will strike the bottom on the settling basin in the settling zone provided that its flow length equals or exceeds the depth. (This is also expressed as Vo = H/t, where H is particle height above the basin floor as the particle enters the settling zone; and t is time of particle residence in the settling zone.) Therefore, flow length must be greater than or equal to basin depth at the 2-year, 24-hour storm. Longest practicable flow lengths are preferred.

This is the same principle used to design wastewater settling basins and is discussed in *Unit Operations and Processes in Environmental Engineering* (Reynolds, 1982):

> Vo is the settling velocity of the smallest particle size that is 100 percent removed [i.e., Vo = Vs]. When a particle of this size enters the [settling] basin at [the surface of the water] it has a trajectory [of 45^0] and intercepts the [basin bottom] which is at the downstream end [of the basin]. The detention time is equal to the depth, H, divided by the settling velocity, Vo, or
>
> $$t = \frac{H}{Vo}$$
>
> The detention time, t, is also equal to the length, L, divided by the horizontal velocity, V, or
>
> $$t = L\,V^{-1}$$
>
> The horizontal velocity, V, is equal to the flow rate, Q, divided by the cross-sectional area, HW, or
>
> $$V = Q\,(HW)^{-1}$$
>
> Combining equations…to eliminate V gives

$$t = L\ W\ H\ Q^{-1}$$

Equating [the] equations gives

$$L\ W\ H\ Q^{-1} = H\ Vo^{-1}$$

Rearranging yeilds

$$Vo = Q\ (LW)^{-1}$$

or

$$Vo = Q\ Ap^{-1}$$

where Ap is the plan area of the basin.

As extended detention basins are open to wind and operate in stormy conditions, a dimensionless constant of 1.2 should be added when calculating Ap (see Management Practices of Nonpoint Source Pollution Control [citation]. Therefore, Ap is calculated as:

$$Ap = 1.2\ Q/Vo$$

Derivation of $Pl = 87.6Q^{1/2}$ *and* $Pl = 120Q/Ws + 7Ws$ *required pond are:* As expansion and contraction constants require adjusting the pond length based on the settling zone width, long, thin settling zones allow for the most efficient use of land. To account for unimpeded expansion and contraction during the 2-year, 24-hour storm, a pond's surface area (Ap) must equal the settling area (As) plus 2 times the settling area width (Ws) to account for expansion at a 4:1 ratio and 1.5 times the settling area width to account for contraction at a 3:1 ratio:

$$Ap = As + 3.5\ Ws$$

Therefore, ponds tend to become significantly less efficient where width is greater than length.

A pond's length (Pl) is a function of its settling area length (Ls) plus its settling area width times 7.

$$Pl = Ls + 7\ Ws$$

If the desired width of a pond is known, for a pond where:

$$Q = As\ Vo/1.2$$

Pond length can also be calculated in relation to Q by substituting:

$Ls = As/Ws$ where $Ls >$ depth of pond (e.g., 6 feet)

which yields:

$Pl = As/Ws + 7Ws$

and substituting:

$As = 120Q$

which yields:

$Pl = 120Q/Ws + 7Ws$

If pond length is known, then width can also be calculated but requires, but requires rearrangement and conversion to the quadratic form, which results in the following

$Ws = (Pl \pm (Pl^2 - 3360Q)^{1/2})/14$

If the settling area is square (i.e., $Ls = Ws$ and $Ws = As^{1/2}$), then substitute Ws for Ls in the equation:

$Pl = 8As^{1/2}$

Then:

$Pl = 8Ws$

And substituting 120Q for As, yeilds:

$Pl = 8(120Q2)^{1/2}$ or $Pl = 87.6Q^{1/2}$

5.5 Outlet Protection

a) The channel immediately below a facility outfall should be designed as necessary to prevent erosion and conform to natural topography. An energy dissipater shall be appropriately designed as necessary to control erosive conditions at the outlet for at least the two-year frequency storm by use of a plunge pool or a riprap pad and sized for peak discharge velocities. Allowable velocities shall be based on actual cover and soil conditions. The maximum permissible velocities are as follows:

Table 11-S1-2. Maximum Permissible Velocity (ft/sec)

Soil Texture	Bare Channel	Channel Vegetation Condition		
		Poor	*Fair*	*Good*
Sand, silt, loam, sandy loam, loamy sand, loam and muck	2.0	2.0	2.5	3.5
Silty clay loam, sandy clay loam, clay, clay loam, sandy clay, silty clay	2.5	3.0	4.0	5.0

Source: Engineering Field Manual for Conservation Practices, USDA Soil Conservation Service, 1979.

b) If a facility outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established around the cleared areas adjacent to the channel/stream.
c) To convey potential peak storm event discharges from the structure, an armored emergency spillway should be provided if a fill embankment is used. The spillway shall be armored with riprap or other alternative that protects subgrade soils from erosion during the design event. The armoring shall also include a filter fabric and gravel filter. The spillway shall extend beyond the toe-of-slope in a manner to prevent scour of the embankment toe.

5.6 Low Flow Channels

a) Low flow channels prevent erosion by routing the runoff that first enters an extended detention facility during the initial period of a storm event, and also the final portion at the end of a storm to the facility's outlet.
b) The low flow channel should extend from each inlet to the lip of the lower stage of the structure outlet or to the lowest point of the structure but it does not extend through the forebay.
c) Low flow channels should be constructed of rip-rap (or other appropriate protection) to prevent scouring and erosion of the structure floor.
d) These channels should be designed for the peak design flow into the structure, using Manning's equation for open channel flow which is as follows:

$$V= (1.49/n) (R^{2/3} s^{1/2})$$

where, $v = Q/A$ = average velocity of flow, ft/s
n = roughness coefficient of the channel
$R = A/P$, the cross-sectional area divided by the wetted perimeter, ft
S = hydraulic gradient (slope of the channel) ft/ft

5.7 Outlet Structure

a) The outlet structure should be located within the embankment for maintenance access, safety and aesthetics. Design shall include the use of cutoff walls along outlet pipes to minimize the potential for piping.
b) Lockable covers and manhole steps within easy reach of valves and other controls should provide access to the interior of the riser.

c) If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches, but sized to convey the desired design storm.

5.8 Underground Detention Systems

a) Design of underground systems shall consider the need to periodically remove sediment from the system. As such, the underground system shall be constructed with materials large enough that allow sediment to be removed from throughout the system. Access shall be provided at both ends of the system, including at both ends of parallel runs of the system, with no run longer than 150 feet unless access ports are provided at a minimum of 150 feet intervals.
b) Access shall also be provided directly over the inlet(s) and outlet(s) to the system (See Figure 11-S1-2).
c) System header pipes shall be provided at both system inlet and outlet to distribute flow evenly throughout the system. System header pipes shall be never be a smaller diameter than the inlet pipe. If more than one inlet pipe is proposed, the header pipe shall be capable of conveying the total flow into the system.
d) A buoyancy analysis is required for any system where maximum seasonal groundwater is above the floor of the system.

5.9 Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In extended detention facilities, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

a) Facilities should be designed with a non-clogging outlet, such as a weir, or by incorporating trash racks for culverts and orifice openings.
b) When a weir is used, the minimum slot width should be 3 inches.
c) No orifice should be less than 6 inches in diameter unless a trash rack is added to prevent clogging.
d) Trash racks should be installed at a shallow angle (80-85 degrees).
e) Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir. A half-round pipe that extends at least 12 inches below the outlet invert can be used to minimize passing floatables.
f) Riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the facility, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line facilities.
g) Outlet structures should be resistant to frost heave and ice action in the facility.

5.10 Landscaping/Vegetation

Constructing landscaped extended detention facilities can enhance their aesthetic value. Aquatic plantings around the edge of the facility can provide pollutant uptake, stabilize the soil at the edge of the facility, and improve habitat.

a) Wetland plants should be encouraged in a facility design when the structure intersects the groundwater table.
b) Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
c) Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage.
d) Woody vegetation shall not be planted or allowed to grow on the embankment as well as within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure. However, woody vegetation can be planted along excavated banks of the structure as long as maintenance access is allowed.
e) Existing trees should be preserved in the area around the facility during construction. To minimize warming of stored water and help discourage resident geese populations, this area can be planted with trees, shrubs, and native ground covers.
f) Annual mowing of the facility buffer is only required along maintenance rights-of-way and the embankment.
g) The area of the structure above the facility outlet shall be stabilized with a seed mixture that is tolerant to periodic flooding and is resistant to erosion.

6.0 Construction

a) Avoid soil compaction to promote growth of vegetation.
b) Temporary erosion and sediment controls should be used during construction and sediment deposited in the extended detention facility should be removed after construction. This facility can be used as a temporary sedimentation structure during construction. If so, it may be desirable to temporarily modify the outlet as a stand pipe during construction in order to better manage sediment loads with lower hydraulic loads during construction.
c) Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the *Rhode Island Soil Erosion and Sediment Control Handbook*.
d) Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.

7.0 Inspection and Maintenance

a) Plans for extended detention facilities should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
b) The principal outlet should be equipped with a trash rack, and be generally accessible from dry land.
c) Sediment removal in the forebay should occur at a minimum of every five years or after the sediment storage capacity in the forebay capacity has been filled. A permanent sediment marker shall be installed in the forebay to indicate sediment depths and when cleaning is required.

d) A permanent sediment marker shall be installed in the extended detention structure area to indicate sediment depths and when cleaning is required.
e) Sediment removed from extended detention facilities during construction can be incorporated into on-site fill areas. After construction, this sediment shall be managed in accordance to RIDEM requirements for street sand.
f) Recommended long-term maintenance activities for extended detention facilities are summarized in Table 11-S1-3.

7.1 Maintenance Access

a) A maintenance right of way or easement should extend to the facility from a vehicular point of access.
b) Maintenance access should be at least 10 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
c) The maintenance access should extend to the forebay, inlet, emergency spillway, embankment, where possible.

7.2 Safety Features

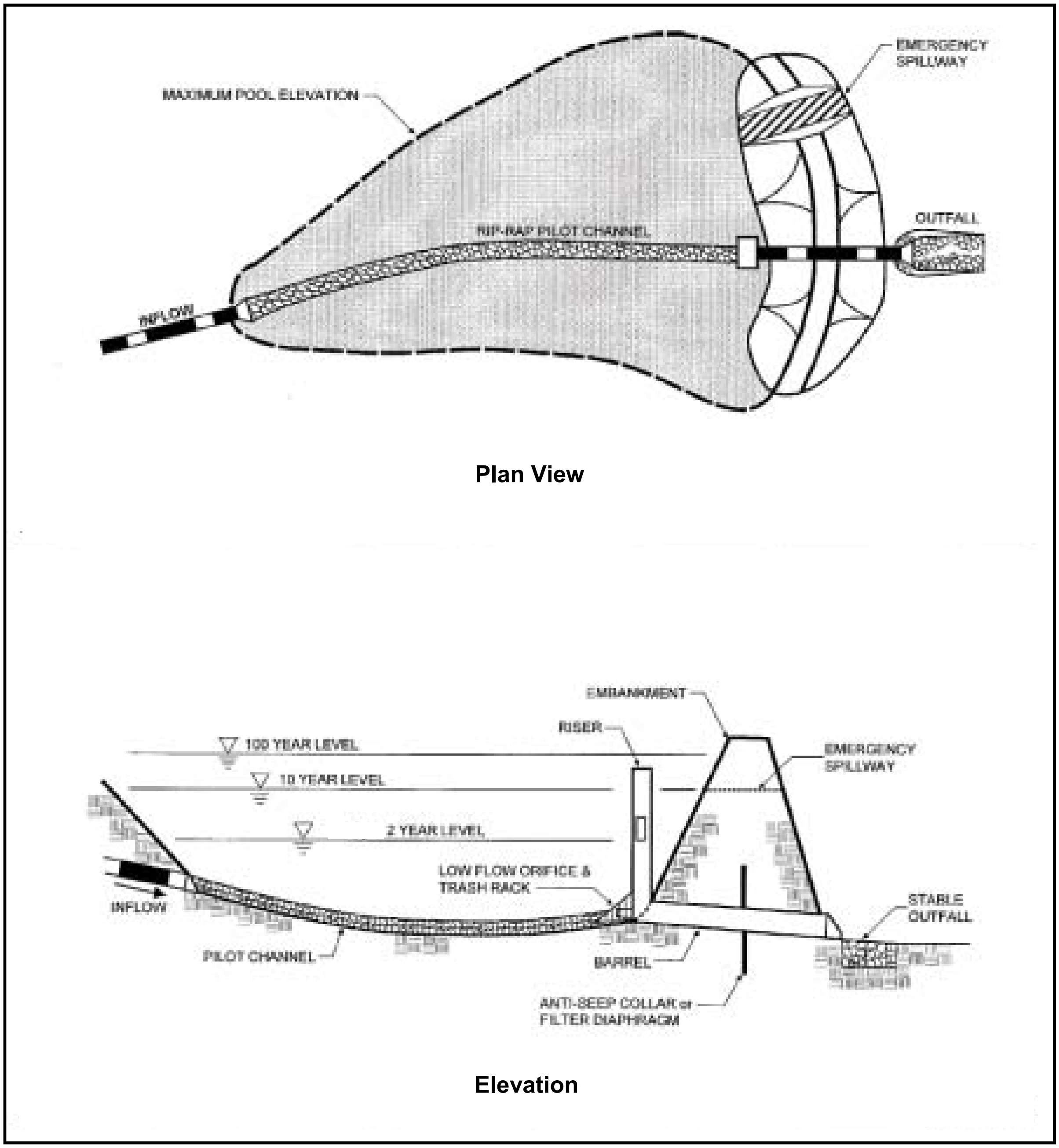
a) Side slopes should not exceed 3:1.
b) The principal spillway opening must not permit access by small children, and walls greater than 4 feet in height must be fenced to prevent a hazard.

Table 11-S1-3. Typical Maintenance Activities for Extended Detention Facilities

Activity	Schedule
• If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
• Inspect for damage. • Note signs of hydrocarbon build-up, and remove if detected. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes. High grass along facility edge will discourage waterfowl from taking up residence.	Monthly maintenance
• Wetland plant management and harvesting.	Annual maintenance (if needed)
• Removal of sediment from the forebay.	5 year maintenance
• Remove sediment when the pool volume has become reduced significantly, or when significant algal growth is observed.	10 year maintenance; more frequent dredging in developing watersheds with significant sediment loads

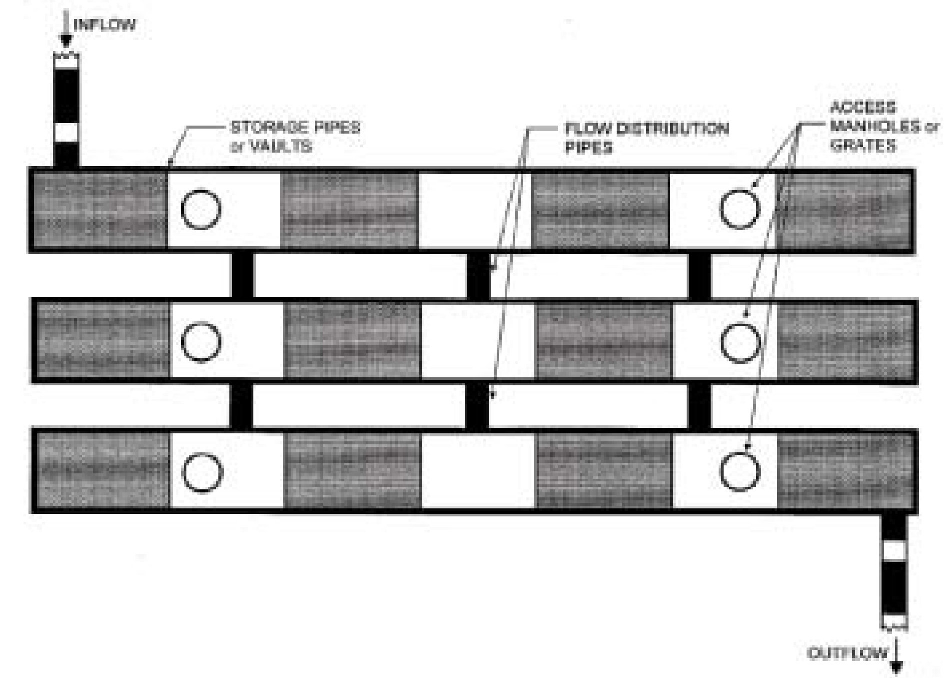
Source: Adapted from WMI, 1997.

Figure 11-S1-1. Extended Detention Facility

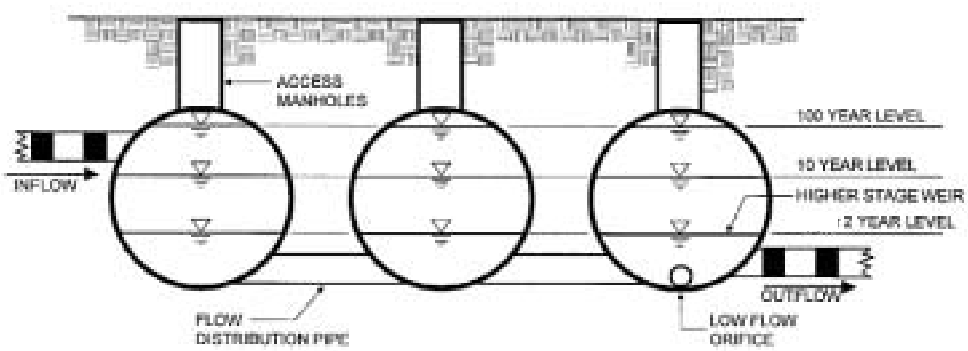


Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-S1-2. Underground Detention System



Plan View



Elevation

Source: Adapted from Center for Watershed Protection, 2000.

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Filtering Practices

Storm Water Management Benefits

Pollutant Reduction

Sediment	■
Phosphorous	■
Nitrogen	■
Metals	■
Pathogens	■
Floatables	◘
Oil and Grease	■
Dissolved Pollutants	◘

Runoff Volume Reduction

Runoff Capture	□
Groundwater Recharge (exfiltration systems only)	◘

Peak Flow Control □

Key:
■ Significant Benefit
◘ Partial Benefit
□ Low or Unknown Benefit

Implementation Requirements

Construction Cost	**High**
Maintenance Cost	**High**

1.0 Description

Storm water filtering practices capture and store storm water runoff and pass it through a filtering media such as sand, organic material, or soil for pollutant removal. Storm water filtering practices generally fall into two categories, which are described in this section:

- Surface filters (including bioretention)
- Underground filters

Storm water filters are primarily water quality control devices designed to remove particulate pollutants and, to a lesser degree, bacteria and nutrients. A separate facility would typically be required to provide channel protection and peak flow control. Most filtering systems consist of four design components:

- Inflow regulation to divert the water quality volume into the facility
- Pretreatment to capture coarse sediments
- Filter surface and media
- Outflow mechanism to return treated flows back to the conveyance system or into the soil

Storm water filtering practices are typically applied to small drainage areas (< 10 acres) and designed as off-line systems to treat the water quality volume and bypass larger flows. The water quality volume is diverted into a pretreatment settling chamber or forebay where coarse solids are allowed to settle, thereby reducing the amount of sediment that reaches the filter. Water flows to the filter surface in a controlled manner, where finer sediment and attached pollutants are trapped or strained out and microbial breakdown of pollutants (e.g., nitrification) can occur. Filtered storm water is then collected below the filter bed or media and either returned to the conveyance system via an underdrain or allowed to infiltrate into the soil (i.e., exfiltration). Due to their similarity to infiltration basins, which were discussed in the previous section, exfiltration systems are not addressed in this section.

Storm water filtering practices are commonly used to treat runoff from small sites such as parking lots and small developments, areas with high pollution potential such as industrial sites, or highly urbanized areas where space is limited. A number of surface and underground storm water filter design variations have been developed for these types of applications. Underground filters can be placed under parking lots and are well-suited to highly urbanized areas or space-limited sites since they consume no surface space. As such, storm water filters are often suitable for retrofit applications where space is typically limited. Storm water filtration systems that do not discharge to the soil (i.e., those contained in a structure or equipped with an impermeable liner) are also suitable options for treating runoff from industrial areas and other land uses with high pollutant potential since the water is not allowed to infiltrate into the soil and potentially contaminate groundwater.

2.0 Design Alternatives

2.1 Surface Filters

a) ***Surface Sand Filter:*** Organic filters are not recommended for use in Rhode Island and, therefore, are not addressed in this manual. The surface sand filter is the original sand filter design, in which both the filter bed and sedimentation chamber are aboveground. Surface sand filters can consist of excavated, earthen basins or aboveground concrete chambers (e.g., Austin Sand Filter). Figure 11-P4-1 and Figure 11-P4-2 depict schematics of two common surface sand filter designs.

b) ***Bioretention:*** Bioretention systems are shallow landscaped depressions designed to manage and treat storm water runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed designed to remove pollutants through physical and biological processes (EPA, 2002). Storm water flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Treated water is allowed to infiltrate into the surrounding soils or is collected by an underdrain system and discharged to the storm drain system or receiving waters. Small-scale bioretention applications (i.e., residential yards, median strips, parking lot islands), commonly referred to as rain gardens, are also described in Chapter Four of this manual as a Low Impact Development design practice. Figure 11-P4-3 depicts schematic designs of several common types of bioretention facilities.

2.2 Underground Filters

a) ***D.C. Sand Filter:*** This underground vaulted filter design was developed by the District of Columbia in the late 1980s. The D.C. Sand Filter includes three chambers. The first chamber and a portion of the second chamber contain a permanent pool of water, which provides sedimentation and removal of floatables and oil and grease. Water flows through a submerged opening near the dividing wall that connects the two chambers, then into the second chamber and finally onto the filter bed. Filtered water is collected by an underdrain system and flows into the third chamber, which acts like a clearwell and overflow chamber (EPA, 2002). A schematic of the D.C. Sand Filter is shown in Figure 11-P4-4.

b) ***Perimeter Sand Filter:*** The perimeter sand filter is an underground vault sand filter that was originally developed in Delaware (also known as the "Delaware Sand Filter") for use around the perimeter of parking lots. The system contains two parallel chambers and a clearwell. Overland flow enters the first chamber through slotted grates. This chamber acts as a sedimentation chamber. Water then flows over weirs into the second chamber, which contains the filter media. Filtered water is collected by an underdrain system and flows into a clearwell before discharging to the storm drain system. A schematic of a perimeter sand filter is shown in Figure 11-P4-5.

c) ***Alexandria Sand Filter:*** The Alexandria Sand Filter, developed in Alexandria, Virginia, is similar to the D.C. Sand Filter in that it consists of three distinct chambers; a sediment chamber, a filtering chamber, and a clearwell. However, the Alexandria design replaces the permanent pool oil/water separator with a gabion barrier that filters and dissipates energy. This variation is a dry system designed to drain between storms. Figure 11-P4-6 shows a schematic of an Alexandria Sand Filter.

d) ***Proprietary Designs:*** A number of proprietary underground media filter designs have been developed in recent years. These systems consist of the same general configuration, with specialized filter media targeted at removal of various particulate and soluble pollutants. Most of these pre-manufactured systems consist of a sedimentation chamber and a filtration chamber that holds a series of canisters with replaceable/recyclable media cartridges.

3.0 Advantages

a) Applicable to small drainage areas.
b) Can be applied to most sites due to relatively few constraints and many design variations (i.e., highly versatile).
c) May require less space than other treatment practices. Underground filters can be used where space limitations preclude surface filters.
d) Ideal for storm water retrofits and highly developed sites.
e) High solids, metals, and bacteria removal efficiency.
f) Bioretention can provide groundwater recharge.
g) Difficult to construct in residential lots.

4.0 Limitations

a) Pretreatment required to prevent filter media from clogging.
b) Limited to smaller drainage areas.
c) Frequent maintenance required.
d) Relatively expensive to construct.
e) Typically requires a minimum elevation difference of approximately 5 feet between the inlet and outlet of the filter.

f) Surface sand filters not feasible in areas of high water tables.
g) Should not be used in areas of heavy sediment loads (i.e., unstabilized construction sites).
h) Provide little or no quantity control.
i) Surface sand filters and bioretention areas can be ineffective during the winter months due to freezing of the filter bed.
j) Surface filters can be unattractive without grass or vegetative cover. Bioretention may be a more aesthetically pleasing alternative due to incorporation of plants.
k) Bioretention areas can be mistaken for unwanted depressions by later property owners. Markings or other notifications should be provided to future property owners.

5.0 Siting Considerations

a) ***Drainage Area:*** The maximum contributing drainage area for most surface and underground filtering practices is between 5 and 10 acres. Filtering practices can be used to treat runoff from larger drainage areas if properly designed, although the potential for clogging increases for drainage areas larger than 10 acres. Bioretention should be restricted to drainage areas of 5 acres or less.

b) ***Elevation Requirements:*** Most storm water filter designs require between 5 and 7 feet of elevation difference between the filter inlet and outlet to allow sufficient gravity flow through the system. The head difference is the difference between the elevation at the inlet to the filter and the outlet pipe. Perimeter sand filters and bioretention areas require as little as 2 feet of head.

c) ***Soils:*** Storm water filtering systems that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Bioretention designs that rely on infiltration can be used only when the soil infiltration characteristics are appropriate (see the Infiltration Practices section of this chapter).

d) ***Land Use:*** Filtering systems are not limited to specific land uses but typically provide the greatest benefits to highly impervious sites.

e) ***Water Table:*** At least 2 feet of separation is recommended between the bottom of the filter and the seasonally high groundwater table to maintain adequate drainage, prevent structural damage to the filter, and minimize the potential for interaction with groundwater.

6.0 Design Criteria

The design criteria are summarized in Table 11-P4-1 below. Design considerations presented in this section are applicable to surface sand filters, bioretention systems, and underground filters. Considerations for specific design variations are also included.

Table 11-P4-1. Minimum Design Criteria for Filtering Practices

Parameter	Design Criteria
Pretreatment Volume	25% of WQV (Impervious area > 1 acre)
Maximum Draining Time	24 hours after storm event
Filter Bed Depth	18 inches (minimum)
Embankments	If a fill embankment is used for a surface filtration facility, follow the embankment requirements prescribed in the wet pond section of the manual.

Source: Adapted from Wisconsin Department of Natural Resources, 2000; NYDEC, 2001; Metropolitan Council, 2001; MADEP, 1997; Lee et al., 1998.

6.1 Pretreatment

a) Pretreatment should be provided to store at least 25 percent of the water quality volume and release it to the filter media over a 24-hour period. Storage and pretreatment of the entire water quality volume (also known as "full sedimentation" design) may be required for sites with more than 1 acre of contributing pavement, on sites with unusually high sediment loads. Alternative technologies sized to remove 80% of the total suspended solids load may be used in lieu of a forebay and its storage requirements.

b) Pretreatment generally consists of a dry or wet sedimentation chamber or sediment forebay. A length-to-width ratio of between 1.5:1 and 3:1 is recommended for the pretreatment area.

c) The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation that is based on Camp-Hazen:

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where:

A_s = sedimentation surface area (ft^2)

Q = discharge rate from drainage area (ft^3/s) $= WQV/86{,}400\,\text{sec}^*$

W = 0.0004 ft/s particle settling velocity recommended for silt

E = sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Therefore, for the purposes of this manual and for evaluating storm water filtering practices in Rhode Island, use

$$A_s = 5{,}750 * Q$$

6.2 Design Volume

a) Surface sand filters should be designed to completely drain in 24 hours or less.

6.3 Filter Bed

a) The filter media for a surface sand filter should consist of fine aggregate (e.g., ASTM C-33, concrete sand). Grain size analysis provided by the supplier is recommended to confirm the sand specification. However, if other media are desired to address specific pollutants, pilot testing is recommended to determine actual hydraulic conductivity. Table 11-P4-2 is the grain size analysis for fine aggregate for concrete by the American Society for Testing and Materials (ASTM).

Table 11-P4-2. Gradation of Fine Aggregate

Sieve Number	Opening Size	Percent Passing (% by Weight)
3/8”	9.5 mm	100
No. 4	4.75 mm	95-100
No. 8	2.36 mm	80-100
No. 16	1.18 mm	50-85
No. 30	600 µm	25-60
No. 50	300 µm	5-30
No. 100	150 µm	0-10

Source: ASTM C-33, 2001;

b) The required filter bed area should be calculated using the principles of Darcy’s Law, which relates the velocity of porous media flow to the hydraulic head and hydraulic conductivity of the filter medium:

$$A_f = \frac{(WQV)(d)}{[(k)(t)(h+d)]}$$

where: $A_f =$ filter bed surface area (ft^2)
$WQV =$ water quality volume (ft^3)
$d =$ filter bed depth (ft)
$k =$ hydraulic conductivity of filter media (ft/day)
$t =$ time for the water quality volume to drain from the system (1 day)
$h =$ average height of water above filter bed during water quality design storm (ft)

c) A typical hydraulic conductivity value for medium sand is 3.5 feet per day. Laboratory analysis is recommended to determine the hydraulic conductivity of the actual filter media.

d) The recommended minimum filter bed depth is 18 inches. Consolidation of the filter media should be taken into account when measuring final bed depth. The surface of the filter bed should be level to ensure equal distribution of flow in the bed.

e) Where possible, the filter bed should be below the frost line.

6.4 Underdrain System

a) The underdrain system should consist of 6-inch diameter or larger PVC perforated pipes reinforced to withstand the weight of the overburden (schedule 40 PVC or greater). A central collector pipe with lateral feeders is a common underdrain piping configuration. The main collector underdrain pipe should have a minimum slope of one percent. The maximum perpendicular distance between two feeder pipes is 10 feet.

b) Perforations in the underdrain piping should be half-inch holes spaced 6 inches apart longitudinally, with rows 120 degrees apart (Metropolitan Council, 2001).

c) The underdrain piping should be set in 1 to 2-inch diameter stone or gravel washed free of fines and organic material. The stone or gravel layer should provide at least 2 inches of coverage over the tops of the drainage pipes. The stone or gravel layer should be separated from the filter media by a permeable geotextile fabric. Geotextile fabric (and an impermeable liner if necessary, see below) should also be placed below the stone or gravel layer.

d) A larger underdrain system (i.e., larger diameter and more frequently spaced underdrain pipes and stone or gravel) may encourage faster draining and reduce the potential for freezing during winter months.

e) Cleanouts should be provided at both ends of the main collector pipe and extend to the surface of the filter.

6.5 Impermeable Liner

a) An impermeable liner (clay, geomembrane, or concrete) should be used for excavated surface sand filters when infiltration below the filter or pretreatment area could result in groundwater contamination, such as in aquifer protection areas or in areas with the potential for high loads for pollutants that could impact groundwater (e.g., soluble metals and organics). Table 11-P4-3 lists recommended specifications for clay and geomembrane liners.

Table 11-P4-3. Liner Specifications

Liner Material	Property	Recommended Specification
Clay	Minimum Thickness	6 to 12 inches
	Permeability	1×10^{-5} cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 millimeters
	Material	Ultraviolet resistant, impermeable poly-liner
		Geotextile fabric should be installed on the top and bottom of the geomembrane to protect against puncture, tearing, and abrasion

Source: [1]NYDEC, 2001; other specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

6.6 Conveyance

a) A flow diversion structure should be provided to divert the water quality volume to the filtering practice and allow larger system design flows to bypass the system.
b) An overflow should be provided within the filtering practice to pass at a minimum the 10-year design storm to the storm drainage system or stabilized channel.
c) Inlet structures should be designed to minimize turbulence and spread flow uniformly across the surface of the filter.
d) Stone riprap or other velocity dissipation methods should be used at the inlet to the filter bed to prevent scour of the filter media.

6.7 Landscaping/Vegetation

a) Planting of surface filters with a grass cover is not recommended since grass clippings can result in reduced permeability or clogging of the filter surface. Grass cover can also conceal the treatment structure or cause it to blend in with surrounding vegetation, thereby potentially resulting in decreased maintenance (i.e., out-of-sight, out-of-mind).
b) Bioretention facilities generally consist of the following hydric zones (Claytor and Schueler, 1996):
   - ***Lowest Zone:*** The lowest zone supports plant species adapted to standing and fluctuating water levels and corresponds to hydrologic zones 2 and 3 in Table A-1 of Appendix A.
   - ***Middle Zone:*** The middle zone supports a slightly drier group of plants, but still tolerates fluctuating water levels. This zone corresponds to hydrologic zones 3 and 4 in Table A-1 of Appendix A.
   - ***Outer Zone:*** The outer or highest zone generally supports plants adapted to drier conditions. This zone corresponds to hydrologic zones 5 and 6 in Table A-1 of Appendix A.

   Plants should be selected to simulate a terrestrial forested community of native species. The following planting plan design considerations should be followed for bioretention areas (Claytor and Schueler, 1996).
   - Use native plant species
   - Select vegetation based on hydric zones
   - Plant layout should be random and natural
   - Establish canopy with an understory of shrubs and herbaceous plants
   - Do not use woody vegetation near inflow locations
   - Plant trees along the perimeter of the bioretention area
   - Do not specify noxious weeds
   - Wind, sun, exposure, insects, disease, aesthetics, existing utilities, traffic, and safety issues should be considered for plant selection and location.

7.0 Construction

a) The contributing drainage area should be stabilized to the maximum extent practicable and erosion and sediment controls should be in place during construction.

b) Filtering systems should not be used as temporary sediment traps for construction erosion and sediment control.
c) The filter media should be wetted periodically during construction to allow for consolidation of the filter media and proper filter media depth. Sand and other filter media should be carefully placed to avoid formation of voids and short-circuiting.
d) Over-compaction of the filter media should be avoided to preserve filtration capacity. Mechanical compaction of the filter media should be avoided. Excavation should be performed with backhoes or light-weight equipment rather than loaders.
e) The underdrain piping should be reinforced to withstand the weight of the overburden.

8.0 Inspection and Maintenance

a) Maintenance is critical for the proper operation of filtering systems. This practice is one of the most sensitive to maintenance.
b) Plans for filtering practices should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
c) Filtering practices should be inspected after every major storm in the first few months following construction. The filter should be inspected at least every six months thereafter. Inspections should focus on:
   - Checking the filter surface for standing water or other evidence of clogging such as discolored or accumulated sediments
   - Checking the sedimentation chamber or forebay for sediment accumulation, trash, and debris
   - Checking inlets, outlets, and overflow spillway for blockage, structural integrity, and evidence of erosion
d) Sediment should be removed from the sedimentation chamber or forebay when it accumulates to a depth of more than 12 inches or 10 percent of the pretreatment volume. The sedimentation chamber or forebay outlet devices should be cleaned when drawdown times exceed 36 hours.
e) Sediment should be removed from the filter bed when the accumulation exceeds one inch or when there is evidence that the infiltration capacity of the filter bed has been significantly reduced (i.e., observed water level above the filter exceeds the design level or drawdown time exceeds 36 hours). As a rule-of-thumb, the top several inches of the filter bed (typically discolored material) should be removed and replaced annually, or more frequently if necessary. The material should be removed with rakes where possible rather than heavy construction equipment to avoid compaction of the filter bed. Heavy equipment could be used if the system is designed with dimensions that allow equipment to be located outside the filter, while a backhoe shovel reaches inside the filter to remove sediment. Removed sediments should be dewatered (if necessary) and disposed of in an acceptable manner.
f) Bioretention areas require seasonal landscaping maintenance, including (Center for Watershed Protection, 2001):
   - Watering plants as necessary during first growing season
   - Watering as necessary during dry periods
   - Re-mulching void areas as necessary

- ❑ Treating diseased trees and shrubs as necessary
- ❑ Monthly inspection of soil and repairing eroded areas
- ❑ Monthly removal of litter and debris
- ❑ Adding mulch annually

g) Recommended long-term maintenance activities for filtering practices are summarized in Table 11-P4-4.

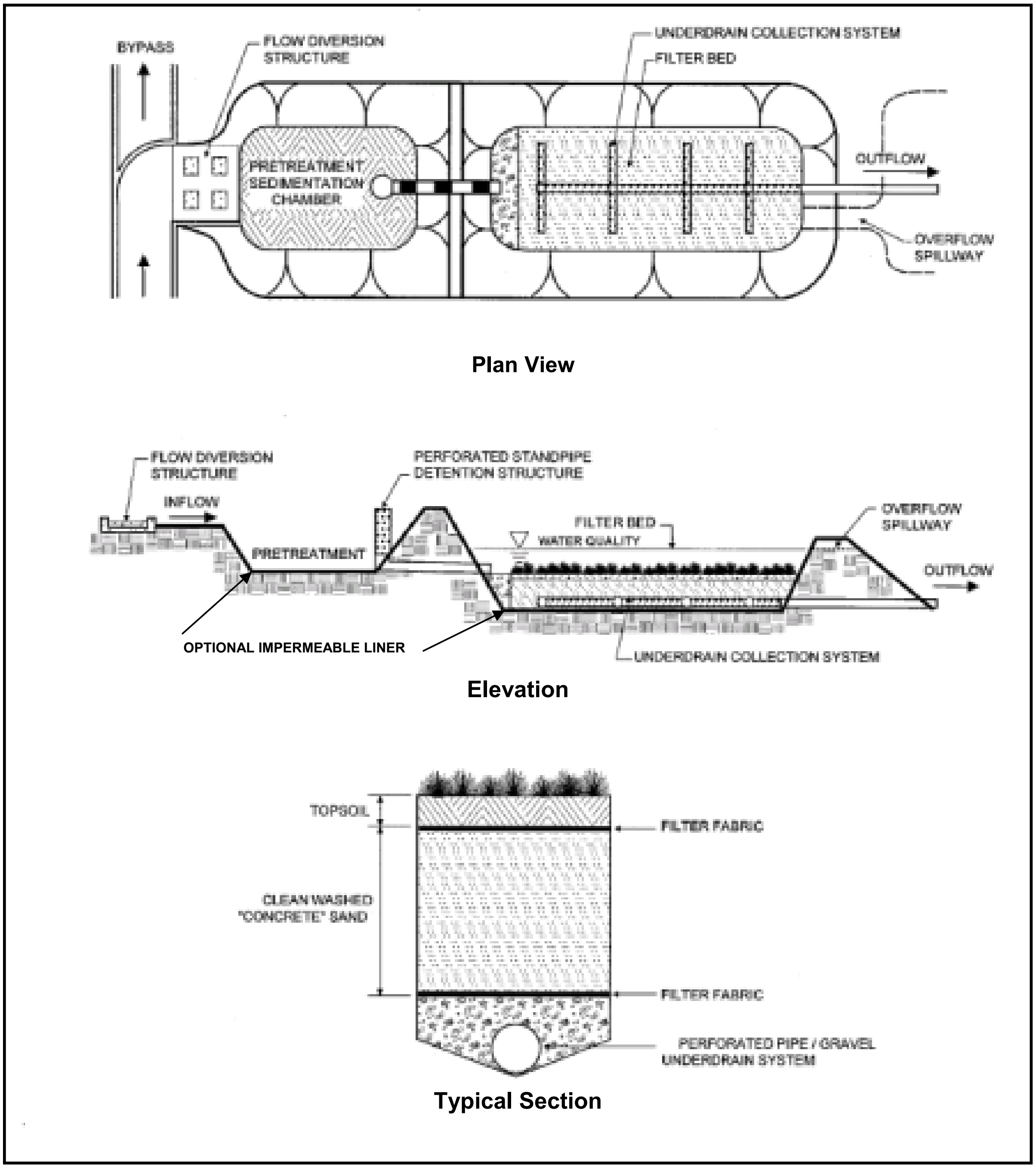
Table 11-P4-4. Typical Maintenance Activities for Filtering Practices

Activity	Schedule
First six months: • Inspect filter, check for: ❑ Standing water or other evidence of clogging ❑ Sediment accumulation, trash, and debris in sedimentation chamber or forebay ❑ Blockages, structural integrity, and evidence of erosion at inlets, outlets, and overflow spillways	After every major storm event that generates 1 inch or more of precipitation
After first six months: • Inspect filter (see above for details)	Every six months
• Remove sediment from sedimentation chamber or forebay	Depth > 12 inches or 10% of pretreatment volume
• Remove sediment from the filter bed	Depth > 1 inch or when infiltration capacity significantly reduced
• Remove and replace top several inches of the filter bed material	Annually
Bioretention areas • Watering plants • Add mulch including re-mulch void areas • Treating diseased trees and shrubs • Inspect soil and repair eroded areas • Remove litter and debris	Seasonally or as necessary

9.0 Cost Considerations

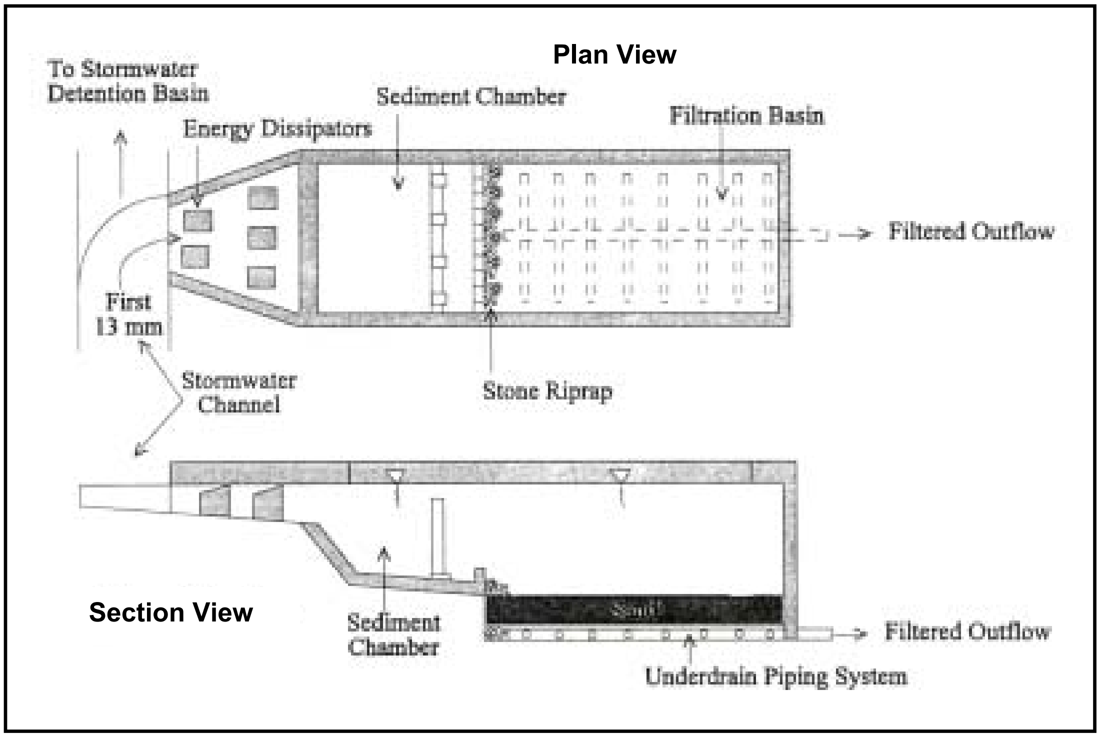
Costs for implementation of storm water filtering practices are generally higher than other storm water treatment practices, but vary widely due to many different filter designs. While underground filters are generally more expensive to construct than surface filters, they consume no surface space, which makes them relatively cost-effective in ultra-urban areas where land is at a premium (EPA, 1999).

Figure 11-P4-1. Earthen Surface Sand Filter



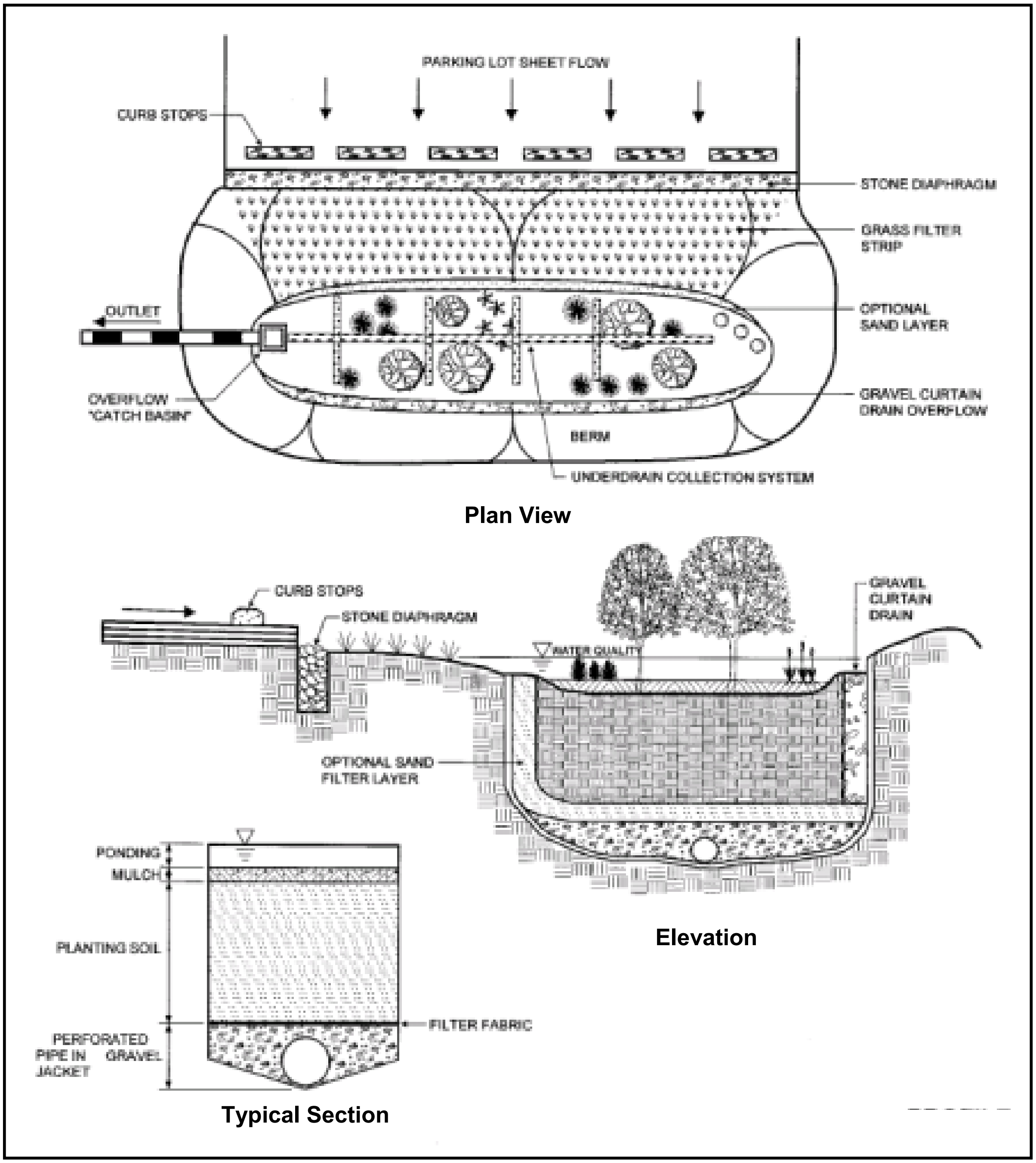
Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-P4-2. Austin Sand Filter



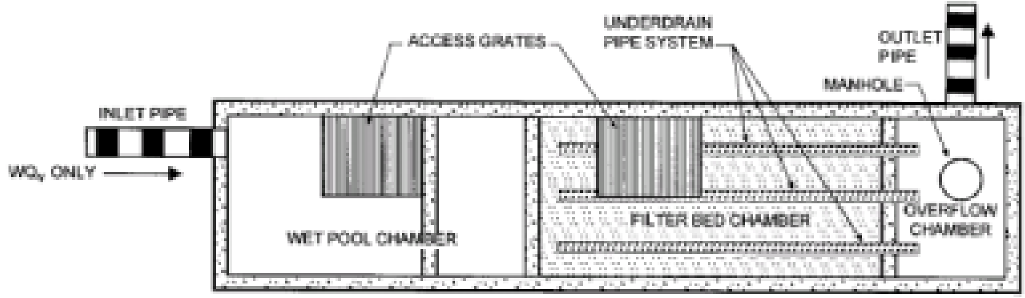
Source: Adapted from FHWA, 1996.

Figure 11-P4-3. Bioretention

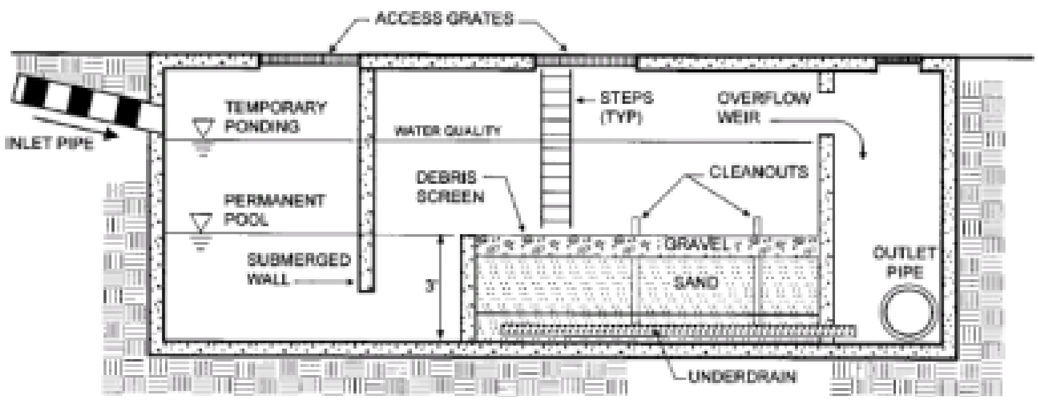


Source: Adapted from Center for Watershed Protection, 2000.

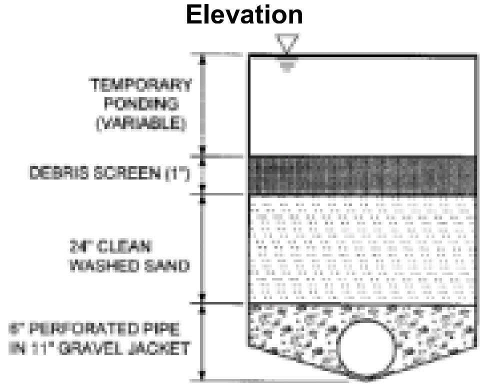
Figure 11-P4-4. D.C. Underground Sand Filter



Plan View



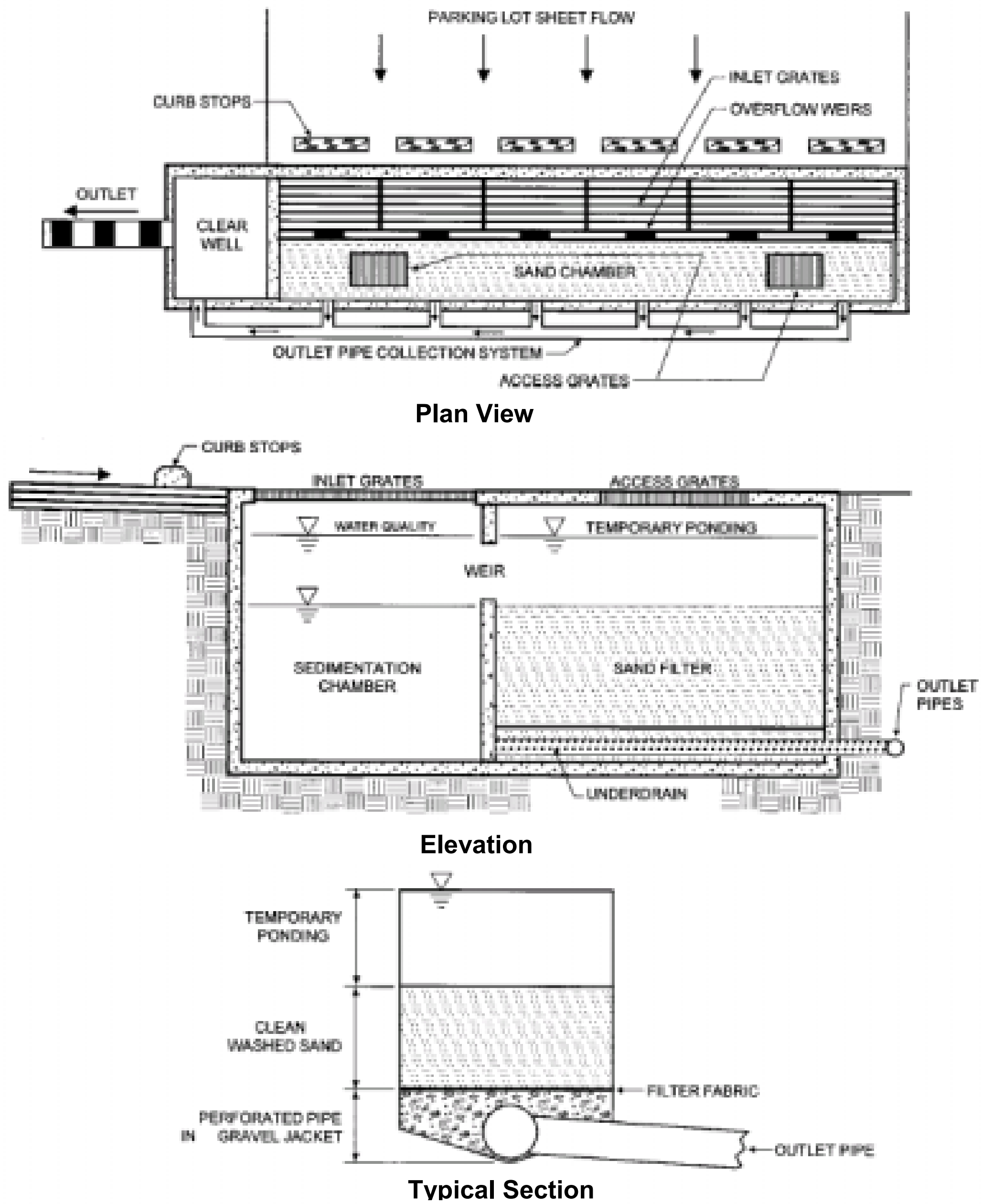
Elevation



Typical Section

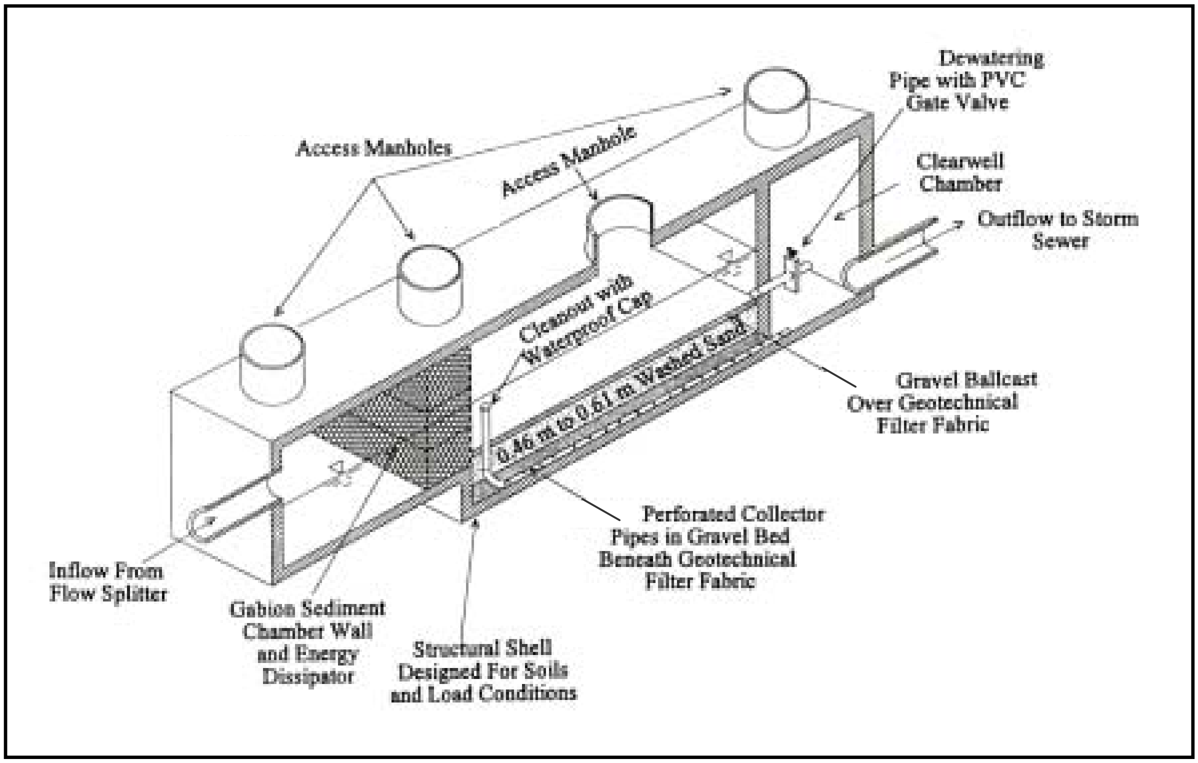
Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-P4-5. Perimeter (Delaware) Sand Filter



Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-P4-6. Alexandria Underground Sand Filter



Source: Adapted from FHWA, 1996.

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Infiltration Practices

Storm Water Management Benefits

Pollutant Reduction	
Sediment	■
Phosphorous	■
Nitrogen	◘
Metals	◘
Pathogens	■
Floatables*	□
Oil and Grease*	□
Dissolved Pollutants	◘
Runoff Volume Reduction	■
Peak Flow Control	■

Key: ■ Significant Benefit
◘ Partial Benefit
□ Low or Unknown Benefit
* Require pre-treatment

Implementation Requirements

Construction Cost	**Moderate**
Maintenance Cost	**High**

1.0 Description

Storm water infiltration practices are designed to capture storm water runoff and infiltrate it into the ground. This section includes three types of infiltration practices:

- Infiltration Trench
- Infiltration Basin
- Subsurface Infiltration Facility

Infiltration practices reduce runoff volume, remove fine sediment and associated pollutants, recharge groundwater, and provide attenuation of peak flows for storm events equal to or less than the design storm. Infiltration practices are appropriate for small drainage areas, but can also be used for larger multiple lot applications, in contrast to rain gardens and dry wells, which are primarily intended for smaller single lots.

Infiltration practices are susceptible to clogging by suspended solids in storm water runoff. Therefore, infiltration systems require pretreatment to remove much of the solids load before entering the infiltration structure. As a result, these structures should be preceded by other primary or secondary treatment practices that are effective in removing coarse solids, as well as oil, grease, and floatable organic material. Infiltration practices are not appropriate in areas that contribute high concentrations of sediment, hydrocarbons, or other floatables without adequate pretreatment.

Because infiltration practices recharge storm water directly to groundwater, they can potentially contaminate groundwater supplies with dissolved pollutants contained in storm water runoff or mobilized from subsurface contamination. Runoff sources that cause particular problems for infiltration facilities include sites with high pesticide levels, and manufacturing and industrial sites with potentially high concentrations of soluble toxicants and heavy metals. Infiltration practices should be carefully sited and designed to minimize the risk of groundwater contamination. Runoff from residential areas (rooftops and lawns) is generally considered the least polluted and, therefore, the safest runoff for discharge to infiltration facilities (Wisconsin DNR, 2000). Rooftop runoff may still have some pollutant loadings such as those associated with atmospheric deposition such as nitrogen.

These facilities can be used both on- and off-line as well as a polishing technique for other BMPs. On-line facilities would infiltrate the entire design storm and thereby both maximize groundwater recharge but eliminate peak flow discharges to surface waters for up to the design storm. Off-line facilities are typically sized to infiltrate the WQV which is diverted into the infiltration facility. As a result, while effective in removing a significant mass of pollutants from a surface water discharge as well as recharging groundwater for most storm events, they are not as effective to manage peak flows from typical drainage system design events (e.g., 10, 25, 100 years storms). Polishing systems are best utilized to remove specific pollutants of concern from a BMP surface water discharge that another BMP could not remove and are typically sized to infiltrate the WQV. For example, an infiltration based, polishing system could be used to reduce the bacteria loading from a surface water discharge from a constructed wetlands, wet pond, or extended detention basin. The following table summarizes recommended design storms for these applications.

Table 11-P3-1. Infiltration Application Design Storms

Application	Design Storm
On-Line	As specified by the governing jurisdiction, local or state, typically between 10 and 100 year storms.
Off-Line	WQV
Polishing Step	WQV

2.0 Design Alternatives

a) **Infiltration Trenches:** Infiltration trenches are shallow, excavated, stone-filled trenches in which storm water is collected and infiltrated into the ground. Infiltration trenches can be constructed at a ground surface depression to intercept overland flow or can receive piped runoff discharged directly into the trench. Runoff gradually percolates through the bottom and sides of the trench, removing pollutants through sorption, trapping, straining, and bacterial degradation or transformation. Infiltration trenches are typically very limited to the drainage area that they can serve. These trenches are also ideally used where space is limited. Trenches can be used as either on-line or off-line devices. However, given their limited hydraulic capacity, they are best used off-line. Utilization of this BMP will require at a minimum RIDEM Groundwater Section, Underground Injection Control (UIC) program permitting.

b) **Infiltration Basins:** Infiltration basins are surface storm water impoundments designed to capture and infiltrate the water quality volume over several days, but do not retain a permanent pool. Infiltration basins can be designed as off-line devices to infiltrate the water quality volume and bypass larger flows to downstream peak runoff discharge control facilities or as combined infiltration/peak runoff discharge flow control facilities by providing detention above the infiltration zone. This section describes off-line basins designed for groundwater recharge and storm water quality control, rather than peak runoff discharge control. However, many of the design principles remain the same with the exception of the increased hydraulic load and the potential for groundwater mounding. The bottom of an infiltration basin typically contains vegetation to increase the infiltration capacity of the basin, allow for vegetative uptake, and reduce soil erosion and scouring of the basin.

c) **Subsurface Facilities:** A number of underground infiltration facilities, including premanufactured pipes, vaults, and modular facilities, have been developed in recent years as alternatives to infiltration trenches and basins for space-limited sites and storm water retrofit applications. Performance of these systems varies by manufacturer and system design. Pollutant removal efficiency is similar to that of infiltration trenches and basins. These underground infiltration facilities require a separate UIC permit from RIDEM. It is the systems owner's responsibility to secure that permit and meet all RIDEM requirements.

3.0 Advantages

a) Promote groundwater recharge and help maintain baseflow in nearby streams.
b) Reduce the volume of runoff, thereby reduce the size and cost of downstream drainage and storm water control facilities.
c) Provide at least partial attenuation of peak flows, thereby reduce local flooding and help maintain streambank integrity.
d) Significantly reduce pollutant load in treated storm water to surface waters. However, some dissolved pollutants may still enter surface waters after being transported by groundwater.
e) Provides the best opportunity for reduction of surface water bacterial loading.
f) Appropriate for small or space-limited sites.

4.0 Limitations

a) Potential failure due to improper siting, design (including adequate pretreatment), construction, and maintenance. Infiltration facilities usually fail for one or more of the following reasons (Wisconsin DNR, 2000):
    - Premature clogging
    - A design infiltration rate greater than the actual infiltration rate
    - Because the facility was used for construction site erosion control
    - Soil was compacted during construction
    - The upland soils or facility walls were not stabilized with vegetation, and sediment was delivered to the facility
    - Sources of sediment in the watershed that could lead to clogging
b) Risk of groundwater contamination depending on subsurface conditions, land use, and aquifer susceptibility.

c) Require frequent inspection and maintenance.
d) Not suitable for storm water runoff from land uses or activities with the potential for high sediment or pollutant loads without pretreatment.
e) Low removal of dissolved pollutants in very coarse soils.
f) Use generally restricted to small drainage areas.
g) Significantly reduced performance in the winter due to frozen soils.

5.0 Siting Considerations

a) ***Drainage Area:*** The maximum contributing drainage area for infiltration facilities should not exceed 25 acres (10 acres is recommended). While theoretically feasible, provided sufficiently permeable soils are present, infiltration from larger contributing drainage areas can lead to problems such as groundwater mounding, clogging, and compaction that would need to be evaluated for larger systems.

b) ***Soils:*** Underlying soils need to have a minimum infiltration rate confirmed by a field investigation acceptable to the reviewing authority. Soils need to generally have a clay content of less than 30 percent and a silt/clay content of less than 40 percent. Suitable soils generally include sand, loamy sand, sandy loam, loam, and silt loam. Recommended soil investigation procedures:
   i) Infiltration rates need to be determined through an appropriate field permeability test that is representative of vertical water infiltration through the soil, excluding lateral flows. A double-ring infiltrometer test is recommended (ASTM, 1994).
   ii) Lab permeability testing should not be used to establish field infiltration rates since they do not adequately represent in-situ or field conditions. Percolation tests used for designing septic systems are also not suitable for determining field infiltration rates.
   iii) Field measured infiltration rates should be reduced by a safety factor of at least two to account for clogging over time. The recommended design infiltration rate is equal to one-half the field-measured infiltration rate.
   iv) Test pits or borings should be used to determine depth to groundwater, depth to bedrock (if within 4 feet of proposed bottom of infiltration facility), and soil type. Test pits or soil borings should be excavated or dug to a depth of 4 feet below the proposed bottom of the facility
   v) Infiltration tests, soil borings, or test pits should be located at the proposed infiltration facility to identify localized soil conditions.
   vi) Testing should be performed by a qualified professional (e.g., registered Professional Engineer, Soil Evaluator licensed in the State of Rhode Island, or registered Soil Scientist with S.S.S.S. N.E).
   vii) For infiltration trenches, one infiltration test and one test pit or soil boring should be performed per 50 linear feet of trench. A minimum of two infiltration tests and test pits or soil borings should be taken at each trench. The field measured infiltration rate should be based on the slowest rate obtained from the infiltration tests performed at the site.
   viii) One infiltration test and one test pit or soil boring should be performed per 5,000 square feet of facility area. A minimum of three infiltration tests and test pits or soil borings should be performed at each facility. The field measured infiltration

rate of the facility should be based on the slowest rate obtained from the infiltration tests performed at the site.

The field infiltration rate is approximately equal to the hydraulic conductivity of the soil under the following conditions:

- Steady infiltration under saturated conditions (hydraulic gradient equal to 1)
- Water table does not encroach above the bottom of the infiltration facility

Table 11-P3-2. Minimum Infiltration Rates of NRCS Hydrologic Soil Groups

Group	Soil Texture	Minimum Infiltration Rate (in/hr)
A	Sand, loamy sand, or sandy loam	0.30 – 0.45
B	Silt loam or loam	0.15 – 0.30
C	Sandy clay loam	0.05 – 0.15
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	0 – 0.05

Note: Tabulated infiltration rates are approximately equal to saturated hydraulic conductivities.
Source: U.S. Soil Conservation Service, 1986.

c) ***Land Use:*** Infiltration practices should not be used to infiltrate runoff containing significant concentrations of soluble pollutants that could pollute groundwater, without adequate pretreatment. Infiltration practices should not be used in areas of existing subsurface contamination that could mobilize pollutants, and may be prohibited or restricted within aquifer protection areas or wellhead protection areas at the discretion of the review authority. Land uses or sites where excessive fine soils could lead to premature clogging are not appropriate for this BMP unless it can be demonstrated that pretreatment such as the use of filtration would prevent clogging.

d) ***Slopes:*** Infiltration facilities are not recommended in areas with natural slopes greater than 15 percent, and should be located at least 50 feet from slopes greater than 15 percent for stability reasons.

Water Table: The bottom of the infiltration structure should be located at least 3 feet above the seasonally high water table or bedrock, as documented by on-site soil testing conducted by a licensed P.E., Class IV soil evaluator, or Society of Soil Scientist of Southern New England (S.S.S.S. N.E.) registered soil scientist. Under drains may be installed to lower the water table. Underdrains may only be perimeter drains that observe the set back requirements and are at least 3 feet below the bottom of the structure.

Recommended water table elevation determinations include the following:

i) Wet Season Determinations – The groundwater table is usually the highest during the months of January through April. To make a proper determination it is necessary to bore an adequate number of holes of convenient size in the proposed infiltration area to a depth of at least 5 feet below the lowest point of the proposed facility. An open perforated pipe at least 4 inches in diameter shall be installed. The pipe shall be capped at the top and mounded to prevent the collection of surface water. Water table observations shall be made using this pipe. It is recommended that multiple observations be made.

ii) Dry Season Determinations – To make a proper determination it is necessary to dig a 10-foot test pit in the proposed infiltration area. In cases where the soil consists of: unconsolidated sand or gravel outwash to a depth of at least 10 feet; has a infiltration rate not greater than 5 min/in; and groundwater or ledge is not encountered within 10 feet of original ground surface, an adjustment factor may be applied to the observed groundwater table in order to correct to the Maximum Groundwater Table Evaluation. If the corrected groundwater table depth is less than 4 feet, or if the ledge and soil other than unconsolidated sand and gravel outwash is encountered less than 10 feet below the original ground surface, the groundwater table must be determined in the wet season. Where soil conditions are other than those previously described, the designer shall collect, evaluate and provide all pertinent information relative to accurate groundwater table evaluation determination in conjunction with the designer's specific professional conclusions and sworn affidavit as to groundwater elevations. Such information to be provided includes the following:

- Groundwater table data from the immediate area;
- Seasonal water elevations in nearby wells and/or surface water bodies;
- USDA Soil Conservation Service data;
- Any other data deemed necessary by the permitting body.

This information may not be available to determine the groundwater table where,

- The groundwater table is estimated to be within 4 feet of the original ground surface; or
- an impervious layer is within 6 feet of the original ground surface; or
- infiltration flows from the proposed facility are anticipated to meet or exceed 2,000 gallons per day; or
- the existing soil is a dark silt loam such as, a Mansfield, Newport, Pittstown and/or Stissing soil series as defined by the United States Department of Agriculture Soil Survey of Rhode Island.

e) Observation Wells: All infiltration facilities shall require an observation well installed to monitor long term performance of the system. These wells should be constructed of perforated 4 inch diameter PVC pipe, extended to the design bottom of the facility, and be securely capped to discourage tampering and vandalism. The observation wells can be secured in position by placing a section of rebar through a perforation in the bottom of the pipe, prior to filling the facility with stone aggregate. Monitoring water level within the pipe at various time intervals after a rain fall event will indicate the infiltration ability and performance of the system. Obviously, if water is standing in a pipe more than 72 hours after a storm event, then failure of the system has occurred and should be addressed through repair or replacement of the facility.

6.0 Design Criteria

Design considerations for infiltration trenches and basins are presented below and summarized in Table 11-P3-3.

Table 11-P3-3. Minimum Design Criteria for Infiltration Practices

Parameter	Design Criteria
Setback Requirements	• 100 feet from on-site sewage disposal systems • 400 feet from community wells • 100 feet from private wells • 25 feet from a property line (this distance may be reduced with proper fencing or landscaping) • 20 feet from any structure • 50 feet from any residential structure • 100 feet upgradient of building foundations (at least 20 feet downgradient from building foundations) • 200 feet from surface water bodies • 50 feet from a designated CRMC buffer zone
Design Volume	Entire water quality volume (100% of WQV)
Pretreatment Volume	25% of WQV (Impervious area > 1 acre)
Maximum Draining Time	72 hours after storm event (entire WQV)
Minimum Infiltration Rate	0.3 in/hr (as measured in the field), lower infiltration rates may be acceptable provided sufficient basin floor area is provided to meet the required WQV and drain time
Maximum Infiltration Rate	7.5 in/hr (as measured in the field); pretreatment required for infiltration rates over 3.0 in/hr. The addition of 6 inches of sandy loam soil can reduce this rate.
Depth	Trench: 3.5 to 10 feet (trench depth).). May be reduces to 2 feet for a single family lot. Basin: 3 feet (ponding depth) recommended, unless used as combined infiltration and flood control facilities

Source: Adapted from Wisconsin Department of Natural Resources, 2000; NYDEC, 2001; Metropolitan Council, 2001; MADEP, 1997; Lee et al., 1998.

6.1 Infiltration Trench

Figure 11-P3-1 depicts a typical schematic design of an infiltration trench. Two infiltration trench designs commonly used for parking lots are shown in Figure 11-P3-2.

6.1.1 Design Volume

a) Infiltration trenches should be designed to infiltrate the entire water quality volume through the bottom of the trench (sides are not considered in sizing).
b) Infiltration trenches should be designed as off-line or polishing practices.

6.1.2 Pretreatment

a) Pretreatment, for an impervious area greater than 1 acre, should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay or other device designed to capture coarse particulate pollutants, floatables, and oil and grease. Alternatively, technologies sized to remove 80% of the total suspended solids load may be used in lieu of WQV storage requirements.

b) If a forebay is used, it shall follow the design requirements prescribed for storm water pond forebays.

c) For an impervious area less than or equal to 1 acre, an oversized deep sump catch basin should be used to treat the runoff from the design storm event. All catch basins should be sealed with a minimum sump depth of 4 feet below the invert to the outlet pipe. The outlet from the catch basin should be equipped with an elbow pipe or trap hood extending a minimum of 2 feet below the invert to facilitate the separation and removal of oil and sediment.

d) A vegetative buffer around the facility is recommended when possible to intercept surface runoff and prolong the life of the facility.

6.1.3 Draining Time

a) Infiltration trenches should be designed to completely drain the water quality volume into the soil within 72 hours after the storm event. Infiltration trenches should completely dewater between storms.

6.1.4 Infiltration Rate

a) A minimum field-measured soil infiltration rate of 0.3 inches per hour is recommended as a practical lower limit for the feasibility of infiltration practices. Lower infiltration rates may be acceptable provided that the WQV and drain time criteria can be met. Field-measured soil infiltration rates should not exceed 7.5 inches per hour.

b) If the infiltration rate exceeds 7.5 inches per hour, 6 inches of sandy-loam soil should be added to the surface of the trench to decrease this rate.

6.1.5 Trench Surface Area and Depth

a) The bottom area of the trench should be sized to allow for infiltration of the entire water quality volume within 48 hours. The trench bottom area can be calculated using the following equation (Metropolitan Council, 2001):

$$A = \frac{12WQV}{Pnt}$$

where:

$A =$ effective bottom area of trench (ft^2)
$WQV =$ water quality volume (ft^3)
$P =$ design infiltration rate of soil (in/hr) (one-half the minimum field measured infiltration rate)
$n =$ porosity of storage media (0.4 for clean stone)
$t =$ maximum drain time (48 hours)

b) The trench should be sized to hold the entire water quality volume. Therefore, the depth of the trench should be determined based on the water quality volume and the calculated effective bottom area.
c) The bottom of the trench should always extend to 3.5 feet below grade. The depth may be reduced to 2 feet for trenches designed for single family lots.

6.1.6 Storage Media
a) The trench should be filled with clean, washed aggregate with a diameter of 1.5 to 3 inches (porosity of 40 percent). The surface of the trench should be lined with permeable filter fabric and additional washed pea gravel or similar aggregate to improve sediment filtering in the top of the trench.
b) The sides of the trench should be lined with filter fabric. The filter fabric should be compatible with the soil textures and application. The bottom of the trench can be lined with filter fabric or 6 to 12 inches of clean sand. Clean sand is preferred over filter fabric since clogging can occur at the filter fabric layer, and sand restricts downward flow less than fabric. Sand also encourages drainage and prevents compaction of the native soil while the stone aggregate is added.
c) An observation well shall be installed along the trench centerline to monitor the water drainage in the system. The well should consist of a well-anchored, vertical perforated PVC pipe with a lockable aboveground cap (Figure 11-P3-3).
d) Trenches that require storm water to enter the trench from the surface shall not have topsoil placed on the top of the trench.

6.1.7 Conveyance
a) Surface runoff exceeding the capacity of the trench should be conveyed in a stabilized channel if runoff velocities exceed erosive velocities (3.5 to 5.0 feet per second) during design storms. If velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.
b) Storm water outfalls should be designed to convey the overflow associated with the 10-year design storm. If storm drains discharge directly into the stone media below grade, system hydraulics shall be evaluated to confirm that the distribution of flow into the system is adequate to manage peak design flows.
c) For off-line systems, a bypass flow path or pipe should be incorporated into the design of the infiltration facility to convey high flows around the facility via an upstream flow splitter. The bypass should be designed to convey the drainage system design storm.

6.1.8 Landscaping
a) Trees should not be planted around trenches that require storm water to enter the facility's surface, unless, it can be demonstrated that maintenance will prevent clogging of the trench surface by leaves.
b) A vegetative buffer around the trench is recommended to intercept surface runoff and prolong the life of the facility.

6.2 Infiltration Facility (Above Ground Systems)

Figure 11-P3-4 depicts a typical schematic design of an infiltration facility.

6.2.1 Design Volume

a) Infiltration facilities should be designed to infiltrate the entire water quality volume through the bottom of the facility.
b) Infiltration facilities can be used as on-line, off-line or polishing techniques.

6.2.2 Pretreatment

a) Pretreatment should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay or other device designed to capture coarse particulate pollutants, floatables, and oil and grease (if necessary). Pretreatment is required for soils with infiltration rates over 3.0 inches per hour. Alternatively, technologies sized to remove 80% of the total suspended solids load may be used in lieu of WQV storage requirements.
b) If a forebay is used, it shall follow the design requirements prescribed for storm water pond forebays.
c) For an impervious area less than or equal to 1 acre, an oversized deep sump catch basin should be used to treat the runoff from the design storm event. All catch basins should be sealed with a minimum sump depth of 4 feet below the invert to the outlet pipe. The outlet from the catch basin should be equipped with an elbow pipe or trap hood extending a minimum of 2 feet below the invert to facilitate the separation and removal of oil and sediment.
d) Underground systems should also include pretreatment through the use of other structures designed to remove 80% of the total suspended solids loading. This is due to the problems with removing sediments and maintaining underground systems.

6.2.3 Draining Time

a) Infiltration facilities should be designed to completely drain the water quality volume into the soil within 72 hours after the storm event. Infiltration facilities should completely dewater between storms.

6.2.4 Infiltration Rate

a) A minimum field-measured soil infiltration rate of 0.3 inches per hour is recommended as a practical lower limit for the feasibility of infiltration practices. Lower infiltration rates may be acceptable provided that the WQV and drain time criteria can be met. Field-measured soil infiltration rates should not exceed 7.5 inches per hour.
b) If the infiltration rate exceeds 7.5 inches per hour, 6 inches of sandy-loam soil would be allowed to be added to the surface of the facility floor to decrease this rate.
c) Topsoil should be stripped from the floor of the facility to minimize potential for freezing during the winter.

6.2.5 Facility Dimensions and Configuration

a) The facility dimensions can be determined from the required storage volume and maximum depth of the facility. The minimum required storage volume is equal to the water quality volume plus precipitation that falls within the facility during the water quality design storm:

For above ground systems:

$$V = WQV + (P)(A_b)$$

where: V = required facility storage volume, ft^3
WQV = design water quality volume, ft^3
P = design precipitation = 1 inch for WQV storm = 0.083 ft
A_b = facility surface area, ft^2

For below ground systems:

$$V = WQV$$

The minimum bottom area can be calculated using the following equation (Metropolitan Council, 2001):

$$A = \frac{12WQV}{Pt}$$

where: A = effective bottom area of trench (ft^2)
P = design infiltration rate of soil (ft/hr) (one-half the minimum field measured infiltration rate)
t = maximum drain time (48 hours)

This equation conservatively assumes no infiltration during the water quality design storm. Larger volume depths may be required for combined infiltration/peak flow control facilities. The maximum facility depth can be calculated from the following equation:

$$D = Pt$$

where: D = maximum facility depth (in)
P = design infiltration rate of soil (in/hr) (one-half the minimum field measured infiltration rate)
t = maximum drain or ponding time (48 hours)

b) The length and width of the facility can be calculated from the water depth and required facility storage volume, as shown above.
c) The facility shape can be any configuration that blends with the surrounding landscape.
d) The floor of the facility should be graded as flat as possible for uniform ponding and infiltration.
e) The facility side slopes should be no steeper than 3:1 (horizontal:vertical). Flatter side slopes are preferred for vegetative stabilization, easier mowing and maintenance access, and safety.

6.2.6 Conveyance

a) Inlet channels to surface facilities need to be stabilized to mitigate against erosive velocities. Riprap used for this purpose need to be designed to spread flow uniformly over the facility floor. This would include the use of appropriate energy dissipators at the inlets to reduce design storm velocities.
b) For off-line systems, a bypass flow path or pipe should be incorporated into the design of the facility to convey high flows around the facility via an upstream flow splitter. The bypass shall be designed to convey the drainage system design storm.

6.2.7 Landscaping/Vegetation

a) Vegetative buffers are recommended around the perimeter of the facility for erosion control and additional sediment filtering.
b) The bottom and side slopes of the facility should be planted with a dense stand of water-tolerant grass. Plant roots enhance the pore space and infiltration in the underlying soil. Use of low-maintenance, rapidly germinating grasses is recommended. Plants should be able to withstand prolonged periods of wet and dry conditions. Highly invasive plants are not recommended. Recommended plant species generally include those species appropriate for hydrologic zones 3 and 4 in Table A-1 of Appendix A. Loose stone, riprap, or other materials requiring hand removal of debris should not be used on the facility floor.

6.3 Subsurface Infiltration Facility

a) Design of underground systems shall consider the need to periodically remove sediment from the system. As such, the underground system shall be constructed with materials large enough that allow sediment to be removed from throughout the system. Access shall be provided at both ends of the system, including at both ends of parallel runs of the system, with no run longer than 150 feet.
b) Access shall also be provided directly over the inlet(s) and outlet(s) to the system.
c) System header pipes shall be never be a smaller diameter than the inlet pipe. If more than one inlet pipe is proposed, the header pipe shall be capable of conveying the total flow into the system.
d) A buoyancy analysis is required for any system where maximum seasonal groundwater is above the floor of the system.

7.0 Construction

a) Proper construction of infiltration practices is critical to minimize the risk of premature failure.
b) Infiltration practices should not be used as temporary sediment facilities during construction.
c) Infiltration practices should be constructed at or near the end of the development construction. The development plan sheets needs to list the proper construction sequence so that the infiltration facility is protected during construction.
d) Before the development site is graded, the area of the infiltration practices should be roped off and flagged to prevent soil compaction by heavy equipment.
e) Light earth-moving equipment (backhoes or wheel and ladder type trenchers) should be used to excavate infiltration practices. Heavy equipment can cause soil compaction and

reduce infiltration capacity. Compaction of the infiltration area and surrounding soils during construction should be avoided.

f) Smearing of soil at the interface of the structure or trench floor and sides should be avoided.

g) The sides and bottom of an infiltration facility should be raked or scarified after the facility is excavated to restore infiltration rates.

h) The floor of an infiltration facility should be raked or deep tilled after final grading to restore infiltration rates.

i) Appropriate erosion and sediment controls should be utilized during construction, as well as immediately following construction to stabilize the soils in and around the facility.

8.0 Inspection and Maintenance

a) Plans for infiltration practices should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

b) Pretreatment devices should be inspected and cleaned at least twice a year.

c) For the first few months after construction infiltration facilities should be inspected after every major storm. Inspections should focus on the duration of standing water in a facility or in the observation well of a facility after a storm. Ponding water after 48 hours indicates that the bottom of the infiltration facility may be clogged. If the bottom of the facility becomes clogged, all of the stone aggregate and filter fabric must be removed and replaced with new material. The bottom of the facility may need to be tilled to enhance infiltration. Water ponded at the surface of a facility may indicate only surface clogging.

d) After the first few months of operation, maintenance schedules for infiltration practices should be based on field observations, although inspections should be performed at least twice per year. Observations should include accumulated sediment, leaves and debris in the pretreatment device, clogging of inlet and outlet pipes, and ponded water inside and on the surface of the facility. For infiltration facilities, observations should include differential accumulation of sediment, erosion of the facility floor, health of the facility vegetation, and condition of riprap.

e) Prune or trim adjacent trees to prevent leaves from clogging the facility surface.

f) Grass clippings, leaves, and accumulated sediment should be removed routinely from the surface of infiltration facilities. The upper layer of stone and filter fabric may need to be replaced to repair surface clogging.

g) Sediment should be removed from infiltration facilities when the sediment is dry (visible cracks) and readily separates from the floor of the facility to minimize smearing the facility floor. The remaining soil should be tilled and revegetated.

h) The grass in the facility, side slopes, and buffer areas should be mowed, and grass clippings and accumulated trash removed at least twice during the growing season.

i) Recommended long-term maintenance activities for infiltration practices are summarized in Table 11-P3-4.

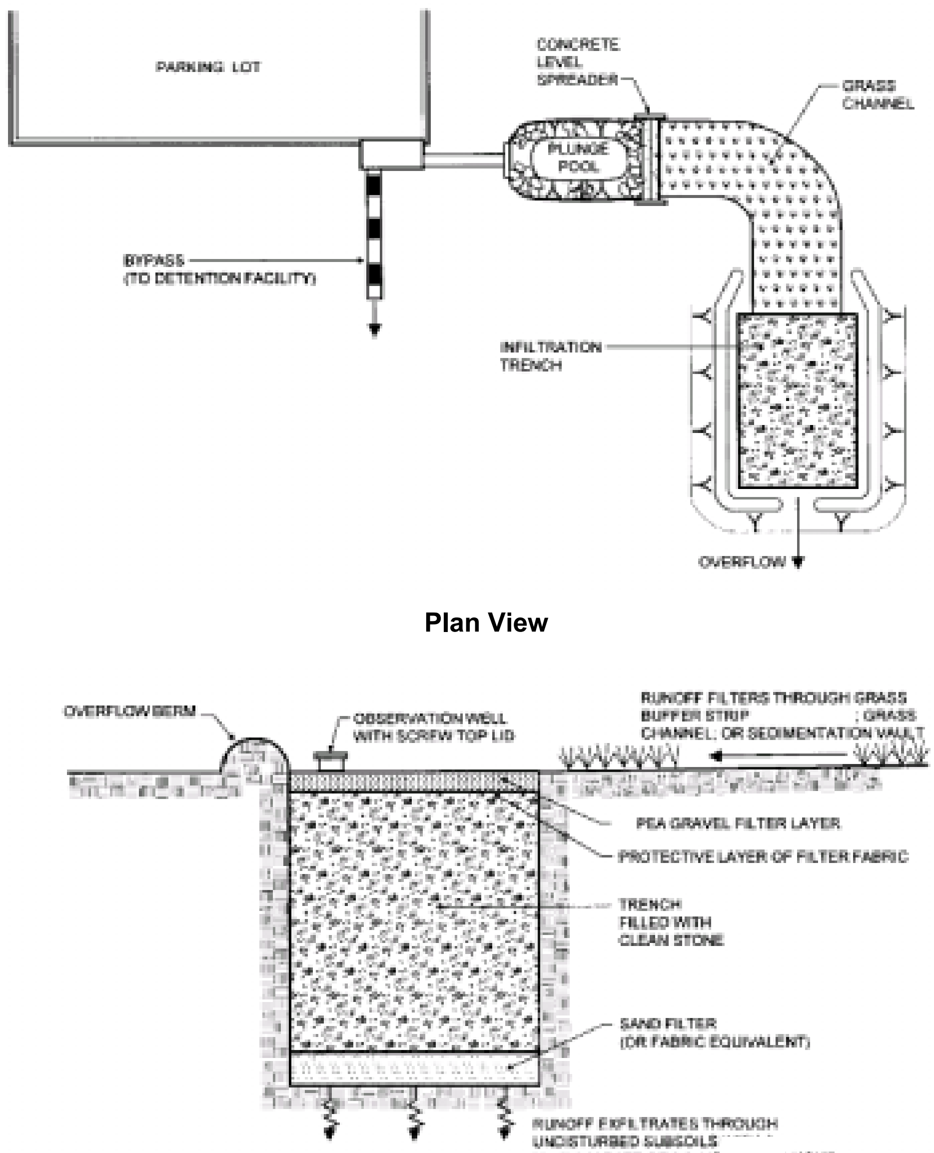
Table 11-P3-4. Typical Maintenance Activities for Infiltration Practices

Activity	Schedule
• Inspect and clean pretreatment devices	Bi-Annually
First few months: • Inspect facilities – focus on the duration of standing water	After every major storm
After first few months: • Inspect facilities	Bi-Annually
• Clean and remove debris from surface of infiltration facility and inlet and outlet pipes. • Till and revegetate surface soil • Replace upper layer of stone and filter fabric.	As needed
• Mow grass in the facility, side slopes and buffer areas • Remove grass clippings and accumulated trash	At least twice during the growing season
• If subdrains are required, monitor water levels in observation wells to confirm proper long term performance of system.	Annually

9.0 Cost Considerations

Costs for implementation of infiltration practices are highly variable from site to site depending on soil conditions and the required pretreatment. The cost per impervious acre treated varies by region and design variant. Infiltration facilities are relatively cost-effective practices because little infrastructure is needed. Maintenance costs for infiltration basins are estimated at 5 to 10 percent of construction costs, while maintenance costs for infiltration facilities are estimated at 20 percent of construction costs (EPA, 2002). Infiltration facilities are more expensive to construct than some other treatment practices in terms of cost per volume of storm water treated. Because infiltration practices have high failure rates if improperly designed, constructed, and maintained, these practices may require frequent replacement, which would reduce their overall cost effectiveness.

Figure 11-P3-1. Infiltration Structure

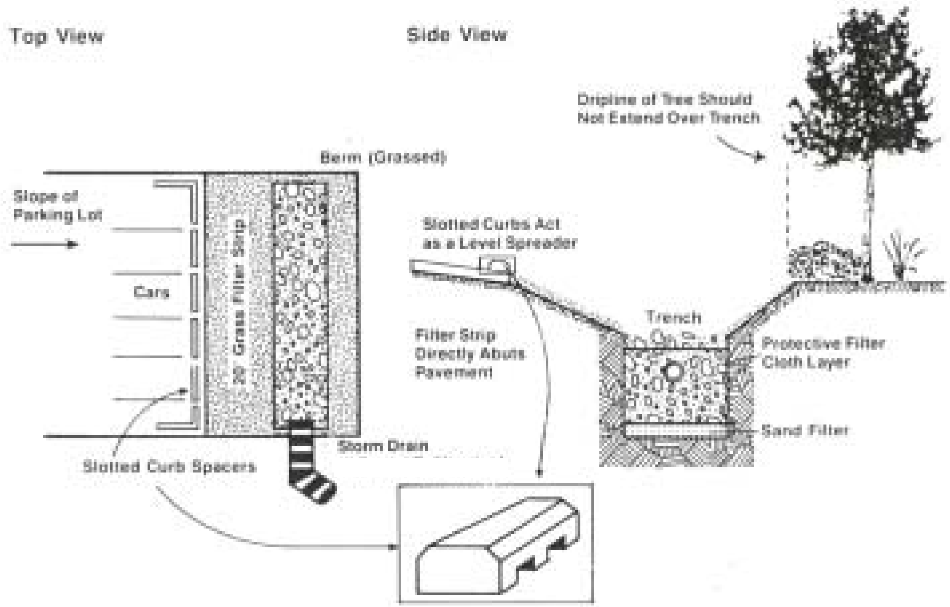


Plan View

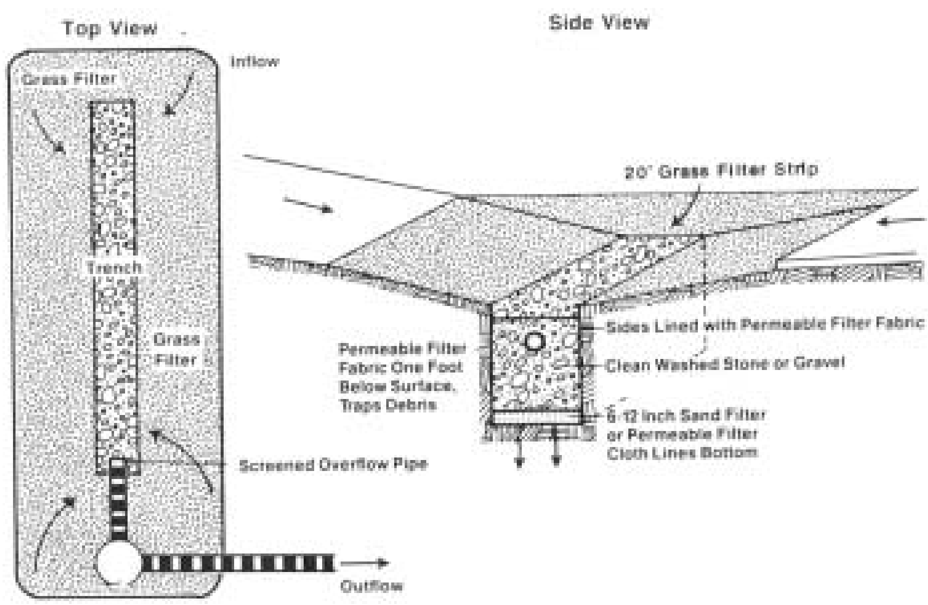
Section

Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-P3-2. Infiltration Trench Designs for Parking Lots



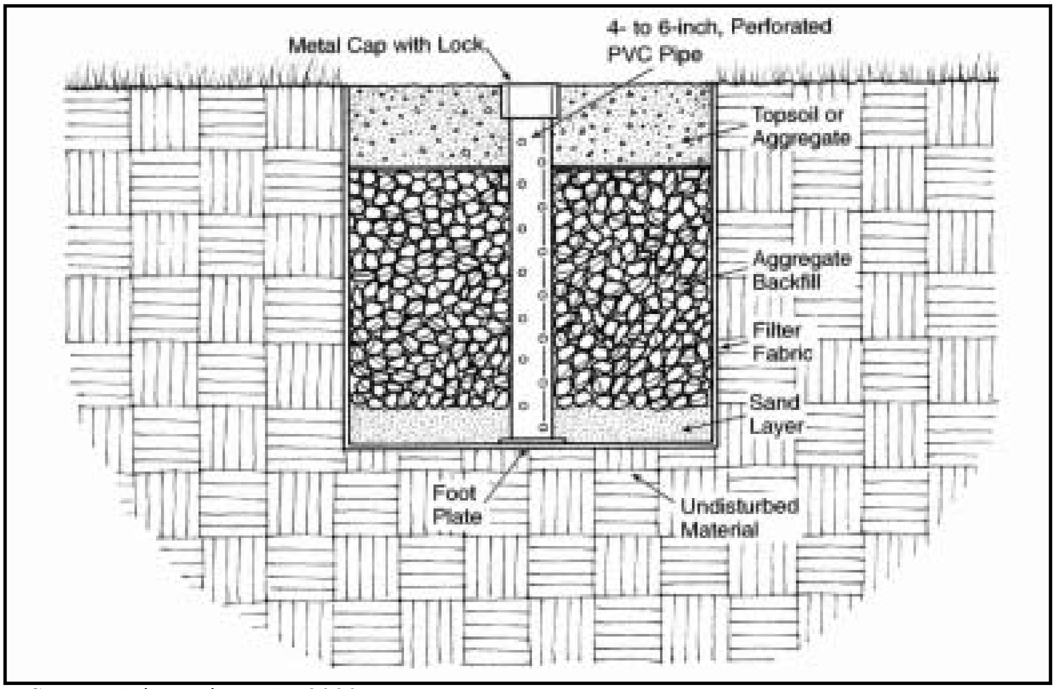
Parking Lot Perimeter Design



Median Strip Design

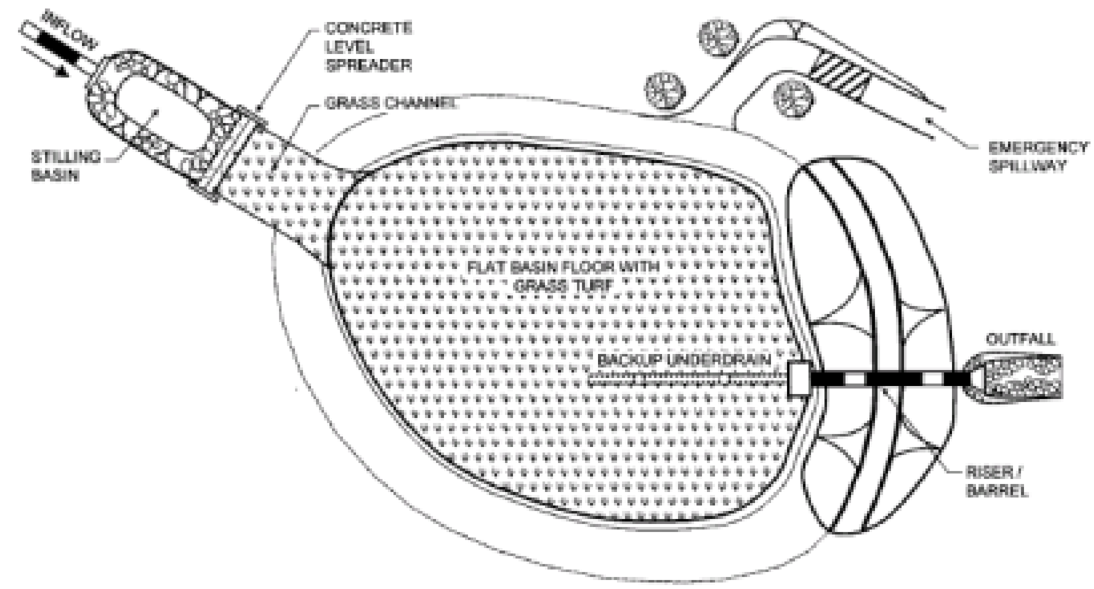
Source: Adapted from Schueler, 1987.

Figure 11-P3-3. Observation Well Detail

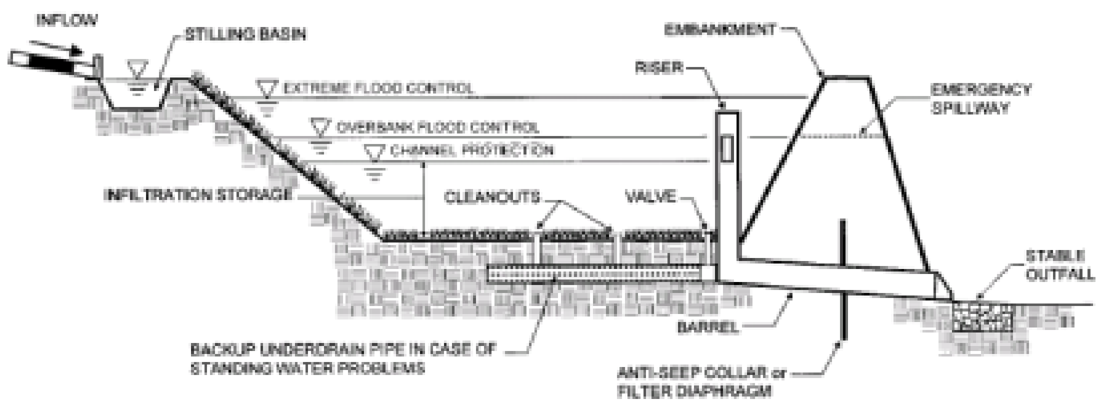


Source: Wisconsin DNR, 2000.

Figure 11-P3-4. Infiltration Basin



Plan View



Section

Source: Adapted from Center for Watershed Protection, 2000.

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Storm Water Wetlands

Storm Water Management Benefits

Pollutant Reduction

Sediment	■
Phosphorous	■
Nitrogen	■
Metals	■
Pathogens	◘
Floatables*	■
Oil and Grease*	■
Dissolved Pollutants	◘

Runoff Volume Reduction □

Peak Flow Control ■

Key: ■ Significant Benefit
◘ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Construction Cost	**High**
Maintenance Cost	**Moderate**

1.0 Description

Storm water wetlands are constructed wetlands that incorporate marsh areas and permanent pools to provide enhanced treatment and attenuation of storm water flows. Storm water wetlands differ from storm water ponds in that wetland vegetation is a major element of the overall treatment mechanism as opposed to a supplementary component. It should be noted that this BMP only applies to constructed wetland systems as opposed to natural wetland systems, which are waters of the State and are protected. This section includes three types of storm water wetlands:

- Shallow Wetland
- Extended Detention Shallow Wetland
- Pond/Wetland System.

While storm water wetlands can provide some of the ecological benefits associated with natural wetlands, these benefits are secondary to the function of the system to treat storm water. Storm water wetlands can be very effective at removing pollutants and reducing peak flows of runoff from developed areas. Removal of particulate pollutants in storm water wetlands can occur through a number of mechanisms similar to storm water ponds including sedimentation and filtration by wetland vegetation. Soluble pollutants can also be removed by adsorption to sediments and vegetation, absorption, precipitation, microbial decomposition, and biological processes of aquatic and fringe wetland vegetation. Storm water wetlands are particularly advantageous compared to other BMPs when nitrogen and/or dissolved pollutants are a concern.

The key to maximizing pollutant removal effectiveness in storm water wetlands is maintaining wet conditions adequate to support wetland vegetation. To achieve this, the constructed wetlands must either intercept the groundwater table or must be lined with an impermeable liner and have a watershed large enough to supply storm flows that will maintain wetness even during dry periods.

Storm water wetland systems should be designed to operate on the plug flow principle where incoming water displaces the water retained in the system from the previous storm event. This is accomplished by maximizing length versus width ratios and/or by creating distinct cells along the treatment path. Ideally, the wetland system would be designed to retain the water quality volume (WQV) between storm events. As a result, storms that generate runoff less than the WQV would be entirely retained while only a percentage of the runoff from storms that generate more than the WQV would be retained. The value provided by this process is that a portion of the "new" polluted runoff is retained, and the "old" treated water is discharged from the wetland, thereby allowing extended treatment of the WQV.

Storm water wetlands should be equipped with a sediment forebay or similar form of pretreatment to minimize the discharge of sediment to the primary treatment wetland. High solids loadings to the system will degrade system performance and result in more frequent cleaning, which could result in additional disturbance to the wetland vegetation. A micropool or permanent pool is also often included just prior to the discharge for additional solids removal.

2.0 Design Alternatives

There are several common storm water wetland design variations. The various designs are characterized by the volume of the wetland in the deep pool, high marsh, and low marsh zones, and whether the design allows for detention of small storms above the permanent pool.

a) ***Shallow Wetland:*** Most shallow wetland systems, also referred to as shallow marsh wetlands, consist of aquatic vegetation with a permanent pool ranging from 6 to 18 inches during normal conditions. Shallow wetlands are designed such that flow through the wetlands is conveyed uniformly across the treatment area. While pathways, streams or other varied water depths could enhance the aesthetic or ecosystem value of the wetland, they could also allow short-circuiting through the wetland thereby reducing the overall treatment effectiveness. As a result, providing a uniformly sloped system is required to maximize treatment performance. In order to enhance plug flow conditions across the wetland, individual wetland cells can be constructed and separated by weirs. Figure 11-P2-1 depicts a typical schematic design of a shallow wetland.

b) ***Extended Detention Shallow Wetland:*** Extended detention shallow wetlands provide a greater degree of downstream channel protection as they are designed with more vertical storage capacity. The additional vertical storage volume provides extra runoff detention above the normal pool elevations. Water levels in the extended detention shallow wetland may increase by several feet after a storm event and return gradually to pre-storm elevations within 24 hours of the storm event. The growing area in extended detention shallow wetlands extends from the normal pool elevation to the maximum water surface elevation. Wetland plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations. Figure 11-P2-2 depicts a typical schematic design of an extended detention shallow wetland.

c) ***Pond/Wetland Systems:*** Multiple cell systems, such as pond/wetland systems, utilize at least one pond component in conjunction with a shallow marsh component. The first cell is typically a wet pond, which provides pretreatment of the runoff by removing particulate pollutants. The wet pond is also used to reduce the velocity of the runoff entering the system. The shallow marsh then polishes the runoff, particularly for soluble pollutants, prior to discharge. These systems require less space than the shallow marsh systems since more of the water volume is stored in the deep pool which can be designed to reduce peak flows through the system. Because of this system's ability to significantly reduce the velocity and volume of incoming peak flows (i.e., flow equalization or dampening), it can often achieve higher pollutant removal rates than other similarly sized storm water wetland systems. Figure 11-P2-3 depicts a typical schematic design of a pond/wetland system.

3.0 Advantages

a) Efficient at removing both particulate and soluble pollutants. Constructed wetlands are one of the most effective storm water treatment practices for removing soluble pollutants.
b) Capable of providing aesthetic benefits.
c) Capable of providing wildlife habitat with appropriate design elements.
d) Provides ability to attenuate peak runoff flows.

4.0 Limitations

a) More costly than most systems.
b) Requires a relatively large land area that is directly proportional to the size of the contributing drainage area.
c) Very sensitive to the ability to maintain wet conditions especially during extended dry weather when there may be significant evaporative losses. Lined systems require a minimum drainage area in order to maintain a permanent pool, which may become difficult during extended dry periods.
d) May cause thermal impacts to receiving waters and thereby are not recommended to discharge directly to cold water fish habitats.
e) Potential breeding habitat for mosquitoes. Circulating water in the permanent pool and proper pool depths should minimize this problem.
f) Wetland systems with steep side slopes and/or deep wet pools may present a safety issue to nearby pedestrians without adequate protection.

g) Unlined systems that intercept groundwater have potential to impact groundwater quality if dissolved pollutants are present in the runoff. This is important in areas sensitive to groundwater quality.
h) Requires more storage volume (i.e., above permanent pool) to attenuate peak flows.
i) Pollutant removal efficiency can be affected in cold climates due to ice formation on the permanent pool and longer particle settling times associated with higher density water during winter months. However, constructed wetlands can be designed to maintain the primary pollutant removal mechanism of sedimentation.

5.0 Siting Considerations

a) ***Drainage Area:*** Storm water wetlands that utilize a liner system to maintain the desired permanent pool should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, minimum contributing drainage areas are twenty-five acres especially for shallow systems. A water budget for the wetlands should be calculated to ensure that evaporation losses do not exceed inflows during warm weather months.

b) ***Groundwater:*** Unlined basins must intersect the groundwater table in order to maintain the desired permanent pool. This is the desired condition to optimize the establishment of a wet pool. In this case, the elevations of the basin should be established such that typical groundwater elevations (not the high groundwater elevation) are equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered, which can be very pronounced in low permeability soils.

   Liners will be required for these systems where groundwater quality is a critical concern such as GAA classified areas or where the system is upgradient to nearby public or private drinking water wells. This is only a precaution since organic sediments that would accumulate in these systems should capture much of the soluble pollutant load prior to discharge to groundwater.

c) ***Land Uses:*** Land uses will both dictate potential pollutants-of-concern as well as potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport and contamination such as from petroleum hydrocarbons, the use of a liner is recommended. Some of these risks can be mitigated by using appropriate pretreatment such as an oil/water separator. An impermeable liner may also not be required depending on risk of downstream contamination. With regard to potential safety issues, adjacent residential land uses pose the greatest risks where water hazards must be considered.

d) ***Baseflow:*** A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer as well as mosquito breeding. This baseflow can be provided by groundwater infiltrating into either the wetland or the collection system above the pond.

e) ***Site Slopes:*** Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume. Steep slopes may also present design and construction challenges as well as significantly increase the cost of earthwork.

f) ***Receiving Waters:*** The sensitivity of receiving waters should be evaluated to determine whether the effects of the warmer storm water discharges from the wetland could be detrimental to cold-water fish or other sensitive aquatic species. Consult RIDEM, Fish and Wildlife Division to determine if the storm water wetland is discharging into a cold water habitat.

g) ***Flood Zones:*** Constructed wetlands should not be located in floodways, floodplains, or tidal lands, especially those that require construction of an embankment, in a manner that will result in flood waters entering the constructed wetland. Floodwaters could flush out stored pollutants or damage pond embankments.

6.0 Design Criteria

Design considerations for storm water wetlands are presented below and summarized in Table 11-P2-1. If the pond also serves to provide a storm water peak flow detention benefit, the design criteria applicable to detention design in the extended detention basin section should be adhered to.

Table 11-P2-1. Design Criteria for Storm Water Wetlands

Parameter	Design Criteria
Setback requirements	• 50 feet from on-site sewage disposal system • 75 feet from private well • 25 feet from property line (this distance may be reduced with proper fencing or landscaping) • 20 feet from any structure • 50 feet from any residential structure • 50 feet from any steep slope below the berm (greater than 15%) • 200 feet from a surface drinking water supply or tributary • 25 feet from a designated CRMC buffer zone
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is the length at mid-depth. Mid-depth is (avg. top width+avg. bottom width)/2
Pretreatment Volume	Forebays are highly recommended for storm water wetlands and sized to contain at least 10% of the WQV. Outlet micropools should also be sized to contain 10% of the WQV
Drainage Area	Minimum contributing drainage area is typically 25 acres for lined systems. Ideally, the watershed to wetland surface area ratio should range between 100:1 to 2.

Underlying Soils	Low permeability soils are best (NRCS Hydrologic Soil Group A and B soils require modifications to maintain a permanent pool unless groundwater is intercepted but may also have greater groundwater fluctuations).
Size	The size of the wetland area will be based on the depth of water available to store the WQV Suggested guidelines for the ratio of wetland to watershed areas is 0.2 (20%) for shallow marshes and 0.01 (1%) for extended detention shallow wetland systems and pond/wetlands.
Depth	Average water levels in the marsh/wetland areas can vary between 0.5 and 1.5 feet. Maximum water depths will depend on the site topography and the design of the system. Forebays and micropools should typically have a permanent pool depth of between 4 and 6 feet.
Sediment Storage	Sufficient volume shall be provided in the forebay to store a total of two years of sediment. This sediment volume shall be calculated using the Universal Soil Loss Equation as outlined in the Rhode Island Sediment and Erosion Control Handbook. This volume shall not be included in the WQV storage.
Emergency Spillway	An emergency spillway shall be provided for any fill embankment. The spillway shall be designed to at least convey the 100-year storm across a stabilized spillway away from the embankment.
Embankment	• Embankments should be designed with a minimum one foot of freeboard during the 100-year storm. This freeboard can include the emergency spillway, however, at least six inches of freeboard should be provided above the 100-year storm water surface elevation in the spillway. These depths can be lessened for low risk embankments (short and no potential downstream risks). • For embankments with a maximum height greater than five feet, a minimum embankment width of 10 feet should be provided for maintenance access. Smaller widths can be employed for smaller embankments. • Maintenance access shall be provided to the forebay and the basin such that heavy construction equipment can be used to remove sediment. • Fill embankments designed to retain the permanent pool require special attention because of the potential for embankment soils to become saturated.

Source: Adapted from MADEP, 1997 and Schueler, 1992.

6.1 Forebay

A sediment forebay shall be provided for all constructed wetland systems. The purpose of the forebay is to provide pretreatment by settling out coarse sediment particles, which will enhance treatment performance, reduce maintenance, and increase the longevity of a storm water pond. A forebay is a separate cell within the pond formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

a) The forebay shall be sized to contain at least 10% of the WQV and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often being four to six feet deep. The goal of the forebay is to remove, at a minimum, particles consistent with the size of medium sand. The forebay must also include additional sediment storage volume that may not be used for WQV calculations.

Alternative technologies sized to remove 80% of the total suspended solids load may be used in lieu of a forebay and its storage requirements.

b) The outlet from the forebay should be designed in a manner to prevent erosion of the embankment and primary pool. This outlet can be configured in a number of ways including a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the basin. The outlet invert must be elevated in a manner such that 10% of the WQV can be stored below it in addition to the required sediment volume.

c) The forebay should have a minimum length to width ratio of 2:1 and a preferred minimum length to width ratio of 3:1.

d) Direct access for appropriate maintenance equipment should be provided to the forebay and may include a ramp to the bottom if equipment cannot reach all points within the forebay from the top. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.

e) A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.

f) A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it is designed to overtop. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the pond, the side slopes of the channel must be armored as well.

g) Sediment storage capacity shall be provided in the forebay as calculated by the Universal Soil Loss Equation in the *Rhode Island Soil Erosion and Sediment Control Handbook*. Adequate volume to store a minimum of two years of sediment storage from the contributing watershed should be incorporated into the forebay.

h) The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation that is based on Camp-Hazen:

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where: A_s = sedimentation surface area (ft^2)
Q = discharge rate from drainage area (ft^3/s) $= WQV/86{,}400\,\text{sec}^*$
W = 0.0004 ft/s particle settling velocity recommended for silt
E = sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Therefore, for the purposes of this manual and for evaluating storm water wetland practices in Rhode Island, use

$$A_s = 5{,}750 * Q$$

6.2 Infiltration Design and Water Balance

Water balance calculations help determine if a drainage area is large enough, or whether it has the right characteristics, to support a permanent pool of water during conditions that occur over an average year. The details of a rigorous water balance are beyond the scope of this manual. However, a simplified procedure is described herein that will provide an estimate of pool viability and identify whether there is a need for more rigorous analysis. Water balance calculations should be done whenever a pond:

- Does not meet the 25 acre drainage area recommendation; or
- Is unlined and not connected to groundwater.

The pool level at the end of each month can be estimated as follows:

$$PL = PL_0 + [BF + (PR \text{ x } AW) + (PR \text{ x } AD \text{ x } RO) - (ET \text{ x } AW) - (I \text{ x } A)] / A$$

where:

PL	=	Pool depth at the end of month (feet)
PL_0	=	Pool depth from the previous month (feet)
BF	=	Total monthly base flow into the pond (acre-feet)
PR	=	Total monthly precipitation (feet)
AW	=	Area of pond (acres)
AD	=	Area of tributary drainage (acres)
RO	=	Runoff coefficient (dimensionless)
ET	=	Monthly potential evapotranspiration (feet)
A	=	Area inundated at depth PL_0 (acres)
I	=	Monthly infiltration (feet)

Water balance estimates should be provided for an entire calendar year, beginning in January and assuming a normal pool level to start. Assumptions regarding the data needed to use this equation are discussed below.

Baseflow: The baseflow variable allows for the inclusion of inflow to a stormwater pond from a stream. Generally, baseflow is assumed to be zero as stormwater ponds are rarely placed across perennial streams. If a pond does receive baseflow, the baseflow must be estimated from observation or through theoretical estimates. Methods of estimation and baseflow separation can be found in most hydrology textbooks.

Monthly precipitation and evapotranspiration: Table 11-P1-3 lists total average monthly precipitation and potential evapotranspiration data to be used for water balance calculations in Rhode Island.

Table 11.P1.3-1.

Average Monthly Precipitation and Potential Evapotranspiration for Rhode Island

Month	Precipitation (feet)	Potential Evapotranspiration (feet)
January	0.36	0
February	0.29	0
March	0.37	0.03
April	0.35	0.13
May	0.31	0.25
June	0.28	0.38
July	0.26	0.47
August	0.33	0.42
September	0.31	0.29
October	0.31	0.17
November	0.37	0.08
December	0.35	0.01

Sources: NOAA-EDIS Climatological Data, 2003, T.F. Green Airport, Warwick, RI. Worldwide Bioclimatic Classification System, 2003, Quonset Point, RI.

Area of the pond: Refers to the average surface area of the permanent pool and should not include the forebay.

Area of tributary drainage: Refers to the watershed or catchment area that contributes runoff to the stormwater pond.

Runoff coefficient: The runoff coefficient is the ratio of runoff (Q) to precipitation (P). Therefore:

$$Ro = Q/P$$

For the purposes of estimating water balance, runoff (Q) may be estimated as follows:

$$Q = 0.9PRv$$

where: P = precipitation for the month being analyzed.
Rv = 0.05 + 0.009i, and i = percent imperviousness in the tributary watershed.

The runoff coefficient may therefore be simplified as follows:

$$Ro = 0.9Rv$$

or substituting 0.05 + 0.009i for Rv:

$$Ro = 0.045 + 0.0081i$$

Area inundated at Plo: In most storm water ponds, the area that is inundated varies with depth. The normal operating pool depth also may be adjusted seasonally to accommodate changes in the water budget. These factors should be accounted for (e.g., averaged) when making calculations.

Monthly infiltration: Infiltration is a very complex subject and is not fully covered here. Full analysis of infiltration depends on soils, water table depth, rock layers, surface disturbance, the presence or absence of a liner in the pond, and other factors. Notwithstanding, infiltration rate is principally governed by Darcy's equation, which can be used as a proxy for the purposes of relatively simplified water balance analysis. Darcy's equation is:

$$I = AKhGh$$

Where: I = infiltration (ac-ft/day)
A = cross sectional area through which the water infiltrates (ac)
Kh = saturated hydraulic conductivity or infiltration rate (ft/day)
Gh = hydraulic gradient = pressure head/distance

Gh can be set equal to 1.0 for pond bottoms and the sides can be assumed insignificant for the purposes of this assessment and therefore drops out of the equation.

As a first cut estimate Table 11.P1.3-2 can be used to determine conductivity.

Table 11.P1.3-2
Saturated Hydraulic Conductivity of Various Materials

Material	Hydraulic Conductivity	
	inches/hour	feet/month
ASTM Crushed Stone No. 3	50,000	3,040,000
ASTM Crushed Stone No. 4	40,000	2,432,000
ASTM Crushed Stone No. 5	25,000	1,520,000
ASTM Crushed Stone No. 6	15,000	912,000
Sand	8.27	502.82
Loamy sand	2.41	146.53
Sandy loam	1.02	62.02
Loam	0.52	31.62
Silt loam	0.27	16.42
Sandy clay loam	0.17	10.34
Clay loam	0.09	5.47
Silty clay loam	0.06	3.65
Sandy clay	0.05	3.04
Silty clay	0.04	2.43
Clay	0.02	1.22

Notes:
Source: Adapted from Atlanta Regional Commission, 2001.

Analysis: If the calculated pool depth at the end of the month is greater than the normal pool depth established at the outlet, then outflow will occur during that month. The quantity is not important as during months with a net outflow. The beginning pool depth for the next month will equal the normal pool depth.

If the water balance predicts that the wetland will dewater, design modifications can be considered which, include:

a) Reducing the infiltration rate by adding a clay layer or synthetic liner
b) Relocating the proposed pond to increase the contributing drainage area
c) Increasing the normal operating pool level.

Limitations on increasing the normal pool level will be imposed by the need for shallow water habitat to support emergent plant vegetation. Short periods, of no more than a month, during which the pond becomes dry may be tolerated in some instances. However, the selection of plants must be tailored to accommodate these adverse conditions and special considerations will be required for the maintenance of the wetland during dry periods.

A 3-foot depth of water must be maintained in some part of the permanent pool (e.g., the sump) at all times to deter mosquito breeding as discussed in section 6.12 of this chapter.

Example: Assume a storm water pond with the characteristics indicated in Table 11.P1.3-3:

Table 11.P1.3-3
Example Storm Water Pond Characteristics

Characteristic	Measure
Area of pond (AW)	0.5 feet
Start depth (Plo)	3 feet
Drainage area (AD)	5 acres
Area inundated (A)	0.25 acres
Infiltration rate (I) (assume clay loam)	5.47 feet
Baseflow (BF)	0 feet
Runoff coefficient (RO) for 70% impervious	0.612

To analyze this data consider the following calculation for January

$$PL = PL_0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)] / A$$
$$PL = 3 + [0 + (0.36 \times 0.5) + (0.36 \times 5 \times 0.612) - (0 \times 0.5) - (5 \times 0.25)] / 0.25$$

PL per the calculation is 12.15 feet; however, water over 3 feet of depth flows out of the pond and so the finishing level is actually 3 feet and there is zero loss to water level in the pond. The calculated PL may then be used as PL_0 in calculations to determine the water balance for February. Table 11.P1.3-4 below provides the calculated water balance for each month in the first year.

Table 11.P1.3-4
Year 1 Water Balance in
Example Storm Water Pond

Month	Precipitation	Potential Evapotranspiration	Starting Level	Finishing Level	Change
January	0.36	0	3.00	3.00	0.00
February	0.29	0	3.00	3.00	0.00
March	0.37	0.03	3.00	3.00	0.00
April	0.35	0.13	3.00	3.00	0.00
May	0.31	0.25	3.00	1.77	-1.23
June	0.28	0.38	1.77	0.00	-1.77
July	0.26	0.47	0.00	0.00	0.00
August	0.33	0.42	0.00	0.00	0.00
September	0.31	0.29	0.00	0.00	0.00
October	0.31	0.17	0.00	0.00	0.00
November	0.37	0.08	0.00	0.14	0.14
December	0.35	0.01	0.14	0.11	-0.03
Net annual change					-2.89

In this example the storm water pond, completely dewaters for 5 months during an average year and experiences a net loss of 2.89 feet over the course of the year. The design is not acceptable and must be altered to ensure appropriate water depth for plantings and to deter mosquitoes.

The following are some examples of how the pond could be redesigned to prevent dewatering:

- A clay liner with conductivity of 1.22 feet/month would maintain its water level at 3 feet during the entire year.
- Increasing the drainage area to 7 acres would maintain a minimum pool depth of 1.72 feet, which occur in July, and maintain zero net loss over the course of the year.

To improve the pond using change in pool depth alone would require a depth of 8 feet, which is the maximum allowed per this manual. The pool would nearly dewater during the months of October – January (see table below), but would regain normal depth by April of the following year (see following table).

Table 11.P1.3-4
Year 1 Water Balance in
Example Storm Water Pond
Assuming an 8-Foot Starting Level

Month	Precipitation	Potential Evapotranspiration	Starting Level	Finishing Level	Change
January	0.36	0	8.00	8.00	0.00
February	0.29	0	8.00	8.00	0.00
March	0.37	0.03	8.00	8.00	0.00
April	0.35	0.13	8.00	8.00	0.00
May	0.31	0.25	8.00	6.77	-1.23
June	0.28	0.38	6.77	4.90	-1.86
July	0.26	0.47	4.90	2.55	-2.35
August	0.33	0.42	2.55	1.39	-1.16
September	0.31	0.29	1.39	0.17	-1.21
October	0.31	0.17	0.17	0.00	-0.17
November	0.37	0.08	0.00	0.14	0.14
December	0.35	0.01	0.14	0.11	-0.03
Net annual change					-7.87

Table 11.P1.3-4
Year 1 Water Balance in
Example Storm Water Pond
Assuming an 8-Foot Starting Level

Month	Precipitation	Potential Evapotranspiration	Starting Level	Finishing Level	Change
January	0.36	0	0.13	0.67	0.54
February	0.29	0	0.67	1.72	1.05
March	0.37	0.03	1.72	7.11	5.40
April	0.35	0.13	7.11	8.00	0.89
May	0.31	0.25	8.00	6.77	-1.23
June	0.28	0.38	6.77	4.90	-1.86
July	0.26	0.47	4.90	2.55	-2.35
August	0.33	0.42	2.55	1.39	-1.16
September	0.31	0.29	1.39	0.17	-1.21
October	0.31	0.17	0.17	0.00	-0.17
November	0.37	0.08	0.00	0.14	0.14
December	0.35	0.01	0.14	0.11	-0.03
Net annual change					0.01

Although this does not present a mosquito-breeding problem as dewatering occurs after the mosquito season, the approach would require careful assessment of plantings to ensure that they could withstand any unusual dry periods. Overall, such an approach would be considered marginal. Note that while the pond experiences a water loss of nearly 8 feet in the first year, the water levels essentially normalize in Year 2 and will continue to start and finish at approximately 0.11 feet for all years thereafter.

6.3 Inlet Protection

a) Inlet areas should be stabilized with riprap or other energy dissipation device to ensure that non-erosive conditions exist for the design storm event.
b) The ideal inlet configuration is above the permanent pool, not submerged, since this can result in freezing and upstream damage or flooding as well as minimize tail water conditions.
c) The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet, but in any case should be located in a manner that meets or exceeds desired length to width ratios. One exception would be allowed for minor outlets where less than 10% of the total volume of runoff enters the basin.
d) Inlet areas should be stabilized to ensure that non-erosive conditions exist for the design storm event.

6.4 Outlet Protection

a) The channel immediately below a pond outfall should be designed as necessary to prevent erosion and conform to natural topography. An energy dissipator shall be appropriately designed as necessary to control erosive conditions at the outlet for at least the two-year frequency storm. Allowable velocities shall be based on actual cover and soil conditions. The maximum permissible velocities are as follows:

Table 11-P2-3. Maximum Permissible Velocity (ft/sec)

Soil Texture	Bare Channel	Channel Vegetation Condition		
		Poor	*Fair*	*Good*
Sand, silt, loam, sandy loam, loamy sand, loam and muck	2.0	2.0	2.5	3.5
Silty clay loam, sandy clay loam, clay, clay loam, sandy clay, silty clay	2.5	3.0	4.0	5.0

Source: Engineering Field Manual for Conservation Practices, USDA Soil Conservation Service, 1979.

b) If a pond outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established around the cleared areas adjacent to the channel/stream.
c) To convey potential flood flows from the basin, an armored emergency spillway should be provided if a fill embankment is used. The spillway shall be armored with riprap or other alternative that protects subgrade soils from erosion during the design event. The armoring shall also include a filter fabric and gravel filter. The spillway shall extend beyond the toe-of-slope in a manner to prevent scour of the embankment toe.

6.5 Outlet Micropools

a) An outlet micropool shall be provided for each wetland system that has a direct discharge to a surface water or to a subsurface infiltration system. Other wetland systems that utilize level spreaders or discharge overland do not require a micropool. The purpose of the micropool is to remove solids that may have "detached" from the wetland system prior to discharge.

b) The micropool shall be sized to store at least 10% of the WQV with a length to width ratio of 2 to 3:1. A water depth of 4 to 6 feet shall be provided in the micropool below the outlet invert to discourage mosquitoes (see also section 6.10).

6.6 Wetland Liners

a) When the permanent pool does not intercept groundwater at its minimum levels, a liner may be needed to maintain minimum water levels. Liners are also necessary for wetland systems that may present a risk to groundwater quality. Table 11-P2-4 lists recommended specifications for clay and geomembrane liners.

b) When used, at a minimum, the liner should extend across the permanent pool area.

Table 11-P2-4. Storm Water Wetland Liner Specifications

Liner Material	Property	Recommended Specification
Clay	Minimum Thickness	6 to 12 inches
	Permeability	$1x10^{-5}$ cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 millimeters
	Material	Ultraviolet resistant, impermeable poly-liner
		Geotextile fabric should be installed on the top and bottom of the geomembrane to protect against puncture, tearing, and abrasion

Source: [1]NYDEC, 2001; all other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

6.7 Pool Benches

a) For forebay and micropool side slopes steeper than 4:1, provide a flat aquatic bench that extends 10 feet inward from the normal shoreline at a depth of 12-18 inches below the normal pool water surface elevation.

6.8 Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In constructed wetlands, maintenance reduction features include techniques to reduce the amount of required maintenance, as well as techniques to make regular maintenance activities easier.

a) Outlets should be designed with non-clogging features, such as a weir, or by incorporating trash racks for culverts and orifice openings.
b) When a weir is used, the minimum slot width should be 3 inches.
c) Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system. Baffle weirs are constructed offset from the outlet and extend below normal ice depth.
d) To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.
e) Riser hoods and reverse slope pipes should draw from at least 12 inches below the low level outlet. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.
f) No orifices should be smaller than 6 inches in diameter unless a trash rack is added to prevent clogging.
g) Trash racks should be installed at a shallow angle (80-85 degrees).
h) Outlet structures should be resistant to frost heave and ice action in the pond.

6.9 Landscaping/Vegetation

High pollutant removal efficiencies are dependent on a dense cover of emergent plant vegetation. Actual plant species do not appear to be as important as plant growth habitat. In particular, plants should be used that have high colonization and growth rates, can establish large surface areas that continue through the winter dormant season, have high potential for treating pollutants, and are very robust in flooded environments. Appendix A contains planting guidance for storm water wetlands. Other landscaping criteria include the following:

a) Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
b) Woody vegetation may not be planted or allowed to grow on the embankment as well as within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure. However, woody vegetation can be planted along excavated banks of the basin as long as maintenance access is allowed.
c) The best depth for establishing wetland plants, either through transplantation or voluntary colonization, is within approximately six inches of the normal pool elevation.
d) Existing trees should be preserved in the area around the wetland during construction. It is desirable to locate forest conservation areas adjacent to ponds and wetlands. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.
e) Annual mowing of the area around the wetland is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
f) The area of the basin above the pond outlet shall be stabilized with a seed mixture that is tolerant to periodic flooding and is resistant to erosion.

6.10 Mosquito Deterrence

Mosquitoes are known vectors for a number of diseases in Rhode Island, including West Nile Virus (WNV). Incidence of mosquito-borne disease like WNV as well as public concern for associated health risks is expected to rise in coming years. Mosquitoes present a serious health risk that must be mitigated to the extent possible.

Mosquitoes from the Culex genus present the greatest concern as they are capable of breeding very opportunistically in small amounts of water (e.g., tires, aluminum cans, buckets, dysfunctional pools, bird baths, etc.), mature very quickly (7 days from hatching to adult) and can breed multiple generations in a season (i.e., every 12 days). Culex mosquitoes easily breed in catch basins and other underground structures that retain water as these structures provide pools (e.g., sumps in catch basins) and reduced risk of predation. Culex and other genera may also breed in stormwater ponds and wetlands with pools that intermittently hold water. Culex are noted nationally to be the most prevalent mosquito genus in stormwater controls; however, there are a wide variety of other genera that occur and present risk.

Three basic forms of mosquito control include (in order of preference to reduce for adverse side effects and environmental risk):

- Source control (i.e., eliminating breeding sites).
- Larval control (i.e., use of larvicide to kill larvae or prevent maturation into adult mosquitoes).
- Spraying for adult mosquitoes.

a) DEM currently provides municipal DPWs with larvicidal pellets for underground catch basins, which contain a 30-day, slow-release growth inhibitor. The growth-inhibitor presents a very low environmental risk as larvae are highly susceptible to very low dosages. Therefore it is primarily recommended for use in areas like underground catch basins where larvacides that float would wash out. Mosquito breeding occurs from late spring to end of summer. As larvicidal pellets are effective for 30 days only, reapplication should occur every 30 days throughout the breeding season. Slow-release briquettes of 90- and 120-day effective life can be purchased.

b) As indicated above, source control is the preferred method of mosquito control as it limits the need for ongoing larvicide application and eliminates any risk--albeit a slight risk--associated with larvicidal applications. Stormwater basins with permanent pools tend to support predators of mosquito larvae. Basins that intermittently flood and dry down can produce mosquitoes. A 3-foot deep sump in a basin can provide a refuge for predators during dry periods.

c) Evolved to avoid surface predation, the Coquilletdia genera of mosquito is noted to live on the roots of emergent vegetation, such as cattails, which may extend into the water column. While modestly prevalent, this mosquito is a known carrier of disease and has been observed in stormwater wetlands throughout the country. Notwithstanding the mosquito risk, emergent vegetation provides valuable treatment of soluble pollutants.

The mosquito adults emerge once a year in early June. Therefore, wherever stormwater treatment systems are designed to include permanent pools with emergent vegetation, application a larvicide in the last week of May is recommended for mosquito control.

7.0 Construction

a) Avoid soil compaction to promote growth of vegetation.
b) Temporary erosion and sediment controls should be used during construction, and sediment deposited in the wetlands should be removed after construction, but before wetland vegetation is planted.
c) Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.
d) Establishment of wetland plantings is critical. As a result, installation should be as directed by a biologist or landscape architect.
e) Upstream areas should be stabilized to the greatest extent practicable prior to planting wetland plants, especially in areas where significant amounts of sediment would collect.
f) Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the *Rhode Island Soil Erosion and Sediment Control Handbook*.

8.0 Inspection and Maintenance

a) Plans for storm water wetlands should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
b) The principal outlet should be equipped with a removable trash rack, and generally accessible from dry land.
c) Sediment removal in the forebay and micropool should occur at a minimum of every five years or before the sediment storage capacity has been filled. A permanent sediment marker should be used to check sediment depths.
d) Inspect twice per year for the first three years to evaluate plant sustainability, water levels, slope stability, and the outlet structure.
e) Perform maintenance outside of vegetative growing and wildlife seasons.
f) Harvesting of dead plant material is not required except in cases where high pollutant removal efficiencies, especially for nutrients, are required.
g) Sediment removed during construction can be incorporated into on-site fill areas. After construction, this sediment shall be managed in accordance to RIDEM requirements for street sand.
h) Recommended long-term maintenance activities for constructed wetlands are summarized in Table 11-P2-5.

8.1 Maintenance Access

a) A maintenance right of way or easement should extend to the pond from a vehicular point of access.

b) Maintenance access should be at least 10 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
c) The maintenance access should extend to the forebay, inlet, emergency spillway, embankment, micropool and outlet where possible.

8.2 Outlet Riser in Embankment

a) The riser should be located within the embankment for maintenance access, safety, and aesthetics.
b) Lockable manhole covers, and manhole steps within easy reach of valves and other controls should provide access to the riser.

8.3 Drain

a) Except where local slopes prohibit this design, each wetland should have a drain pipe that can completely or partially drain the wetland. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the wetland within 24 hours.
b) Care should be exercised during draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction must be notified before draining.
c) Outlet valve shall be located in the riser.

Table 11-P2-5. Typical Maintenance Activities for Storm Water Wetlands

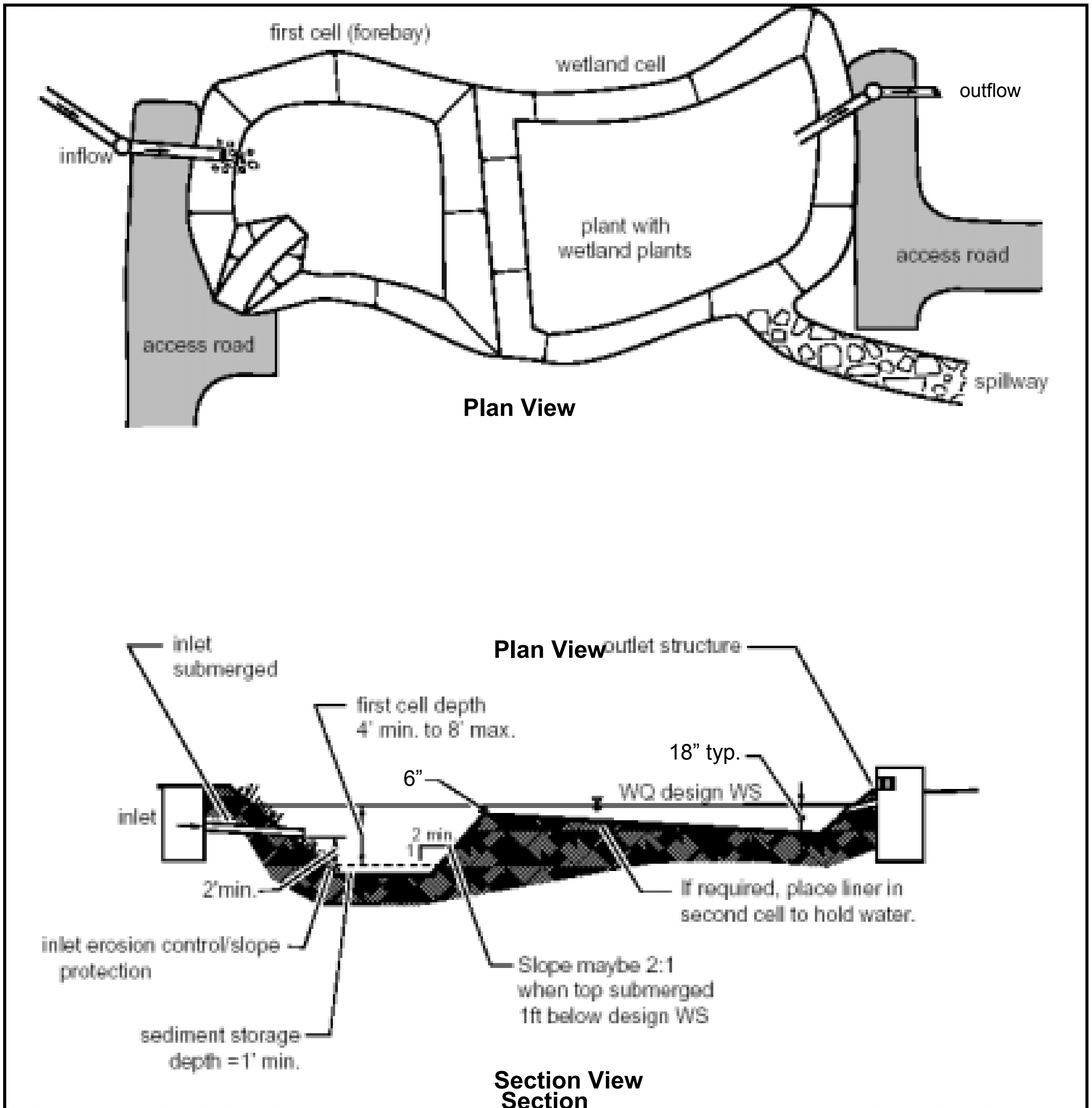
Activity	Schedule
• If necessary, re-plant wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second and third growing seasons.	As needed
• Inspect for invasive vegetation and remove where possible. • Monitor water levels in the wetlands	Semi-annual inspection
• Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility, forebay and micropool. • Examine to ensure that inlet and outlet devices are free of debris and are operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Frequent (3-4 times/year) maintenance
• Harvest wetland plants that have been "choked out" by sediment build-up.	Annual maintenance (if needed)
• Removal of sediment from the forebay and micropool.	As needed, minimum 5 year maintenance
• Monitor sediment accumulations, and remove sediment when the wetland volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	As needed, typical 20 to 50 year maintenance

Source: WMI, 1997.

9.0 Cost Considerations

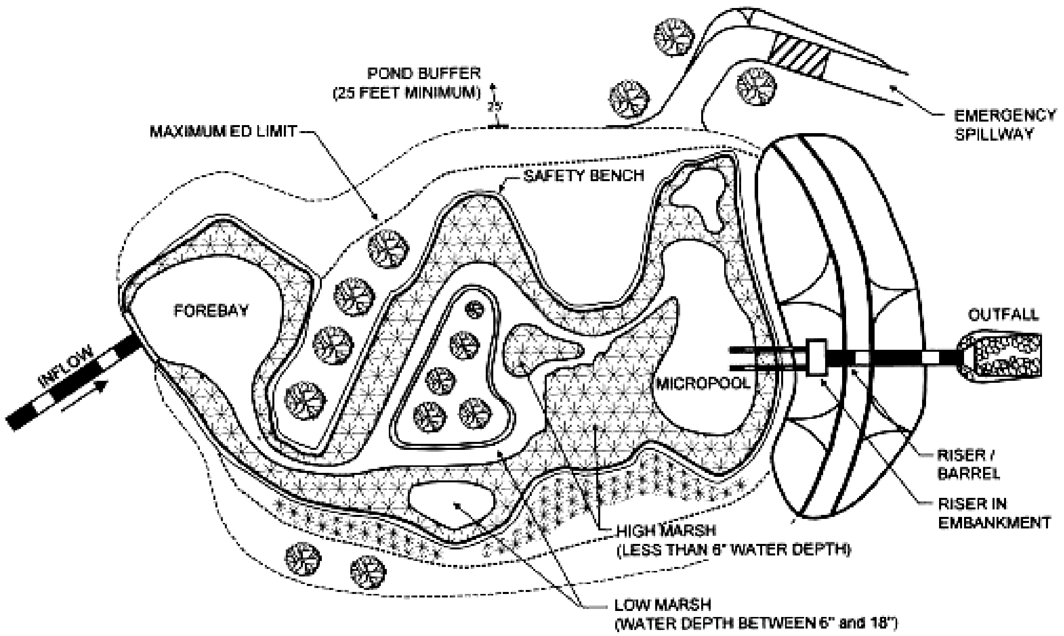
Storm water wetlands are relatively inexpensive storm water treatment practices, but vary widely depending on the complexity of the design or site constraints. The costs of storm water wetlands are generally 25 percent more expensive than storm water ponds of an equivalent volume (Brown and Schueler, 1997). The annual cost of routine maintenance is typically estimated at approximately 3 to 5 percent of the construction cost (EPA Storm Water Wetland Fact Sheet, www.epa.gov/npdes/menuofbmps/menu.htm). Storm water wetlands typically have a design life longer than twenty years.

Figure 11-P2-1. Shallow Wetland

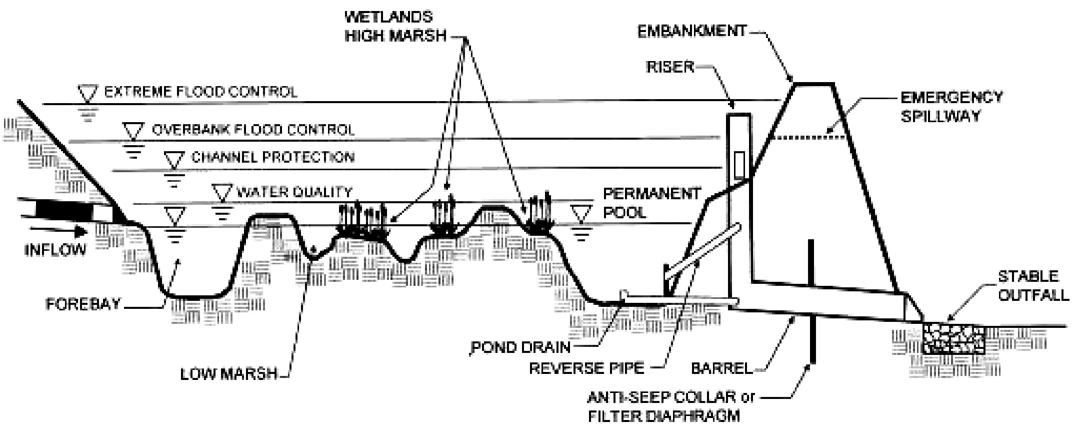


Source: Adapted from King County Department of Natural Resources, 1998.

Figure 11-P2-2. Extended Detention Shallow Wetland



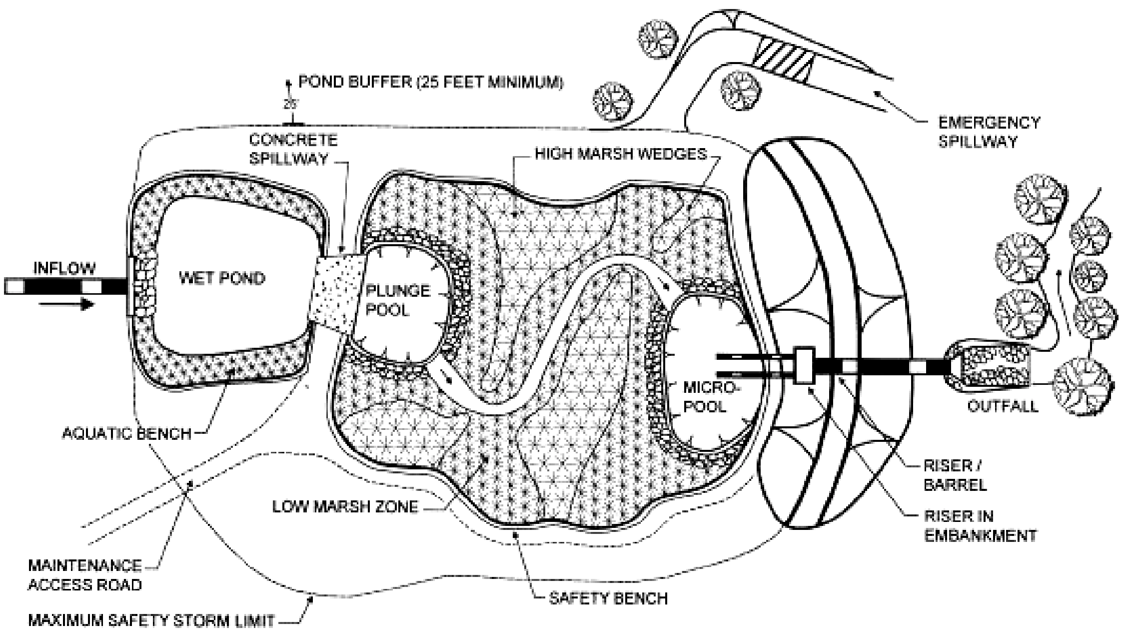
Plan View



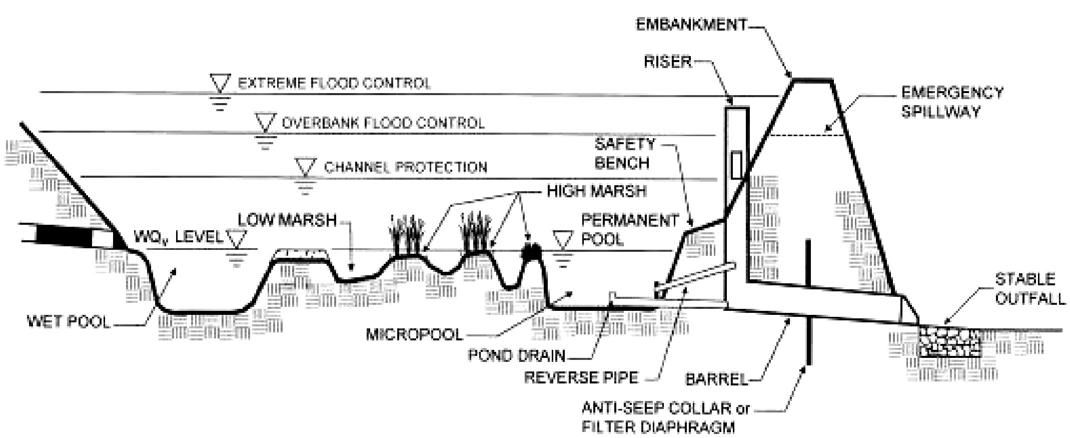
Section

Source: Adapted from NYDEC, 2001.

Figure 11-P2-3. Pond/Wetland System



Plan View



Section

Source: Adapted from NYDEC, 2001.

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